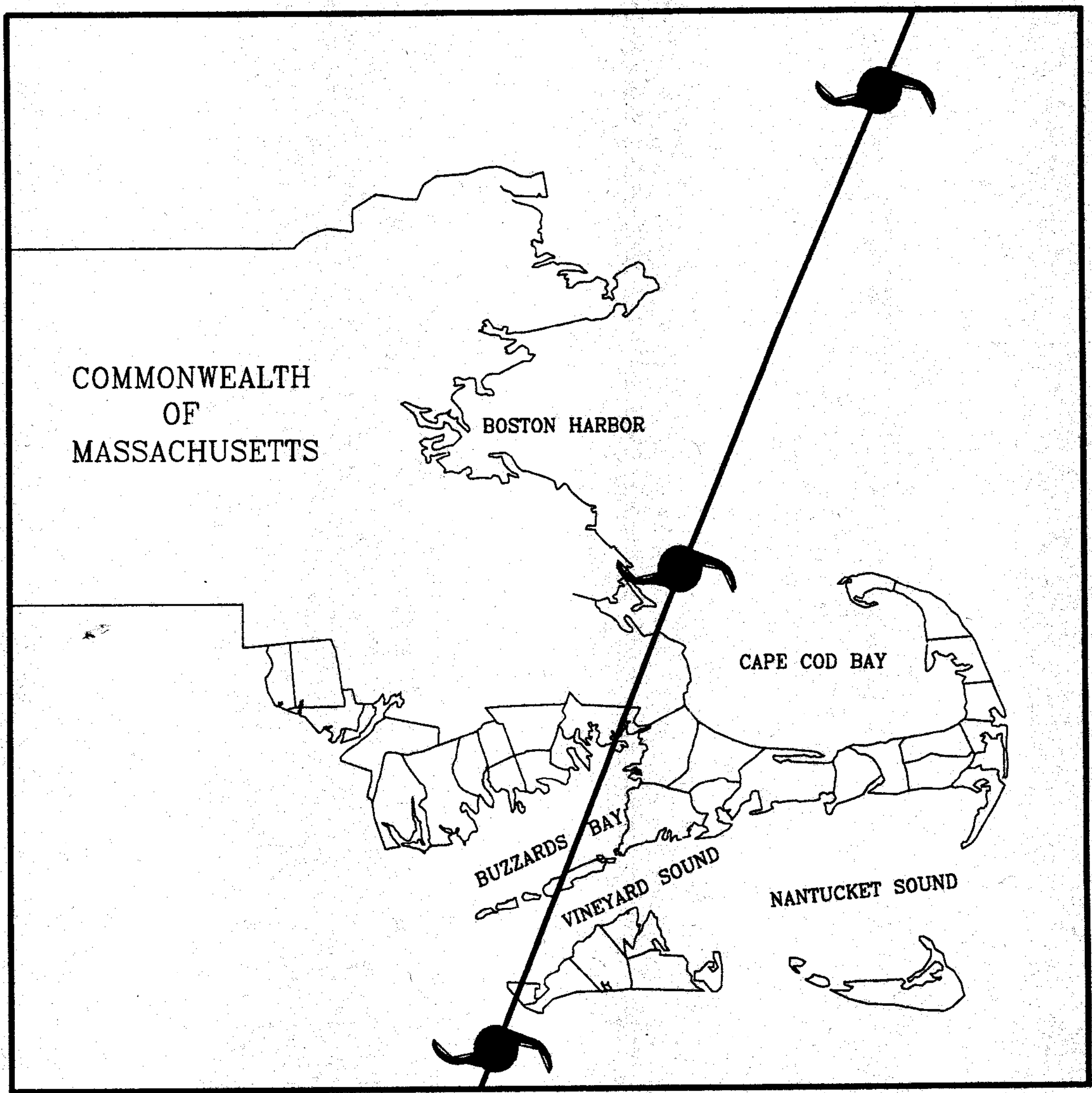
May 1997

Southern Massachusetts Hurricane Evacuation Study Technical Data Report



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This report and its companion atlases were completed as part of the Hurricane Evacuation Study program cosponsored by the Federal Emergency Management Agency and the U.S. Army Corps of Engineers. The purpose of the study is to provide the Massachusetts Emergency Management Agency and coastal communities in Southern Massachusetts with realistic data quantifying the major factors involved in hurricane evacuation decision-making. To accomplish this, the study provides information on the extent and severity of potential flooding from hurricanes, the associated vulnerable population, capacities of existing public shelters and estimated sheltering requirements, and evacuation roadway clearance times. The report also provides guidance on how this information can be used with National Hurricane Center advisories for hurricane evacuation decision-making.

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Executive Summary

AUTHORITY

At the request of the Governor of Massachusetts, the Federal Emergency Management Agency (FEMA) and the US Army Corps of Engineers cooperatively sponsored and conducted the Southern Massachusetts Hurricane Evacuation Study. The study was completed with direct assistance provided by the National Oceanic and Atmospheric Administration (NOAA) and the Massachusetts Emergency Management Agency. Funding was provided by FEMA under the Disaster Relief Act of 1974 and by the Corps of Engineers under its Flood Plain Management Services program authorized in Section 206 of the Flood Control Act of 1960.

SCOPE AND PURPOSE

The purpose of this study was to provide the Massachusetts Emergency Management Agency and coastal communities in southern Massachusetts, including Cape Cod and the Islands, with data quantifying the major factors involved in hurricane evacuation decision-making. The results of this study are not intended to replace existing hurricane preparedness plans but rather to provide state-of-the-art information that can be used to update or revise current plans. The study provides information on the extent and severity of potential flooding from hurricanes, the associated vulnerable population, capacities of existing public shelters and estimated sheltering requirements, and evacuation roadway clearance times. The report also provides guidance on how this information can be used with National Hurricane Center advisories for hurricane evacuation decision-making.

Products developed from the study include the <u>Southern Massachusetts Hurricane Evacuation Study, Technical Data Report</u>, and two companion atlases. The first atlas, the <u>Inundation Map Atlas</u>, shows the areas within communities most vulnerable to flooding from hurricanes. In partnership with local officials, a second atlas, the <u>Evacuation Map Atlas</u>, was developed to identify land areas (evacuation zones) vulnerable to hurricane surge which should be considered for evacuation prior to a hurricane's landfall. The extent of land area included within evacuation zones is based on the surge inundation areas depicted in the <u>Inundation Map Atlas</u>. Evacuation zones encompass all land areas shown to be potentially inundated, as well as areas of land that would be isolated by surrounding surge. The Evacuation Map Atlas also gives the locations of public shelters, medical/institutional facilities, and mobile home/trailer parks.

HAZARDS ANALYSIS

The purpose of the Hazards Analysis was to develop accurate estimates of the potential surge inundation areas resulting from hurricanes. Because this study focuses on protection of the vulnerable population, the study used "worst case" hurricane surge estimates provided by the National Hurricane Center's Sea, Lake, and Overland Surges from Hurricanes (SLOSH) computer model.

The SLOSH model simulated several hundred hypothetical hurricanes of varying intensities, forward speeds, and track directions in order to calculate the potential hurricane surge which may be experienced in coastal communities in southern Massachusetts. Simulations were performed for hurricanes of Saffir/Simpson scale intensity categories 1-4[1] (see Table 1.4 in the report), with forward speeds ranging from 20 to 60 miles per hour, and the storm track directions most likely to affect southern Massachusetts.

The study discusses the difficulties of forecasting the precise tracks of hurricanes, and reports that the average error in the National Weather Service 12 hour track forecast is approximately 60 miles. Because of the uncertainties in hurricane track forecasting, the study assumed that all southern Massachusetts locations are equally vulnerable to each hurricane forecasted to affect the region. Therefore, worst case surge inundation areas provided in the Inundation Map Atlas were developed based on a composite of the critical hurricane tracks and approach directions for all locations. The three surge inundation areas delineated in the Inundation Map Atlas were categorized based on the forward speeds and intensities of the hurricanes modeled using the SLOSH model. These hurricane parameters can be more confidently forecasted by the National Weather Service. Categorized SLOSH model results are shown on Plate iii of the study's Inundation Map Atlas.

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[1]Category 5 hurricanes were omitted from the analysis based upon the National Hurricane Center's recommendation that the cooler ocean waters along the northeast coast of the United States are not capable of sustaining hurricanes of this intensity.

VULNERABILITY ANALYSIS

Approximately one-tenth of Massachusetts' six million residents are located in the 37 study communities (1990 Census). In general, surge vulnerable areas in southern Massachusetts are densely developed with many businesses, multifamily housing units, and beach front and near shore homes. In the 37 southern Massachusetts coastal communities included in this study, there are approximately 205,000 residents potentially vulnerable to hurricane surge from a "weak hurricane scenario" and more than 288,000 residents vulnerable from a "strong hurricane scenario" (see Tables 3.1 and 3.2 in the report).

Communities in which more than 25% of the summer population were found to live in areas vulnerable to "weak" hurricane surge flooding include: Bourne, Chatham, Dennis, Falmouth, Mashpee, Orleans, and Wellfleet in Barnstable County; Fairhaven and Swansea in Bristol County; Gosnold in Dukes County; Nantucket; and Marion, Mattapoisett, and Wareham in Plymouth County. In addition to the above communities, the following communities were found to have more than 25% of the summer population living in areas vulnerable to "severe" hurricane surge flooding: Eastham, Harwich, Provincetown, and Yarmouth in Barnstable County; and Edgartown and Oak Bluffs in Dukes County. The summer population includes permanent residents and those who rent houses for anywhere from one week to the entire summer, but excludes day trippers.

BEHAVIORAL ANALYSIS

The study recognized that not all residents within evacuation zones will respond to officials' recommendations to evacuate their homes. Because varying individual response impacts the evacuation process, a behavioral analysis was conducted to provide an estimate of how the majority of the affected public can be expected to respond to an evacuation recommendation/order. The primary objectives of the behavioral analysis were to determine: 1) how the community's population will respond to evacuation recommendations for a range of hurricane threat situations; 2) the timing of their response; 3) the number of vehicles they will use during evacuations; and 4) the percentage that will seek public shelters.

The Behavioral Analysis concluded that the two overriding factors influencing residents' decisions to evacuate are: 1) actions by local officials; and 2) the perceived degree of hazard at their location. When officials take aggressive action to encourage people to leave, evacuation rates can be expected to increase by approximately 25 to 50 percent. The time at which people mobilize and evacuate is also closely related to local officials' actions.

SHELTER ANALYSIS

A Shelter Analysis was conducted to determine if adequate sheltering exists for the evacuating population. The analysis compared the existing public shelter capacity to the expected public sheltering utilization in each community. As shown in Tables 5.38 and 5.39 in the report, several of the study communities may not have adequate shelter capacity to accommodate the estimated demands.

TRANSPORTATION ANALYSIS

A critical aspect of hurricane evacuation decision-making is knowing how long it will take evacuating vehicles to clear roadways after the public is directed to evacuate (i.e., roadway clearance time). The Transportation Analysis estimated clearance times using a mathematical model of the study area's roadway system which simulated vehicle movements during evacuation scenarios.

Important factors that were varied with each simulation were: the intensity of the approaching hurricane, the response time of evacuees leaving their homes, and the background traffic condition at the start of the evacuation. In addition, the impact that increased population, reduced sheltering, traffic control measures, and reduced evacuee response time could have on clearance times was also determined.

Clearance times ranged from 4½ hours to 13 hours depending on the above factors and the location within the State where the evacuation was modeled. For the Cape, a 10-hour clearance time is recommended for evacuations occurring during the daytime; and an 11-hour clearance time is recommended for evacuations which occur late at night or early in the morning. For all off-Cape study communities, a 7-hour clearance time is recommended for evacuations occurring during the daytime; and a 9-hour clearance time is recommended for evacuations which occur late at night or early in the morning. Chapter Seven discusses the rationale for these recommendations.

Clearance times developed by the Southern Massachusetts Hurricane Evacuation Study do not apply to Dukes and Nantucket counties. It is the intention of the communities of Dukes and Nantucket counties and the Massachusetts Emergency Management Agency to evacuate all non-permanent residents from the islands by ferry or other means possible in response to a hurricane threat. Shelter space will be provided on the islands for permanent residents, and those non-permanent residents who cannot be evacuated.

EVACUATION DECISION-MAKING

Clearance time is one component of the total time required to complete an evacuation. The total evacuation time includes a second component defined as dissemination time (see Figure 7.1 in the report for a diagram illustrating components of evacuation time). Dissemination time refers to the time officials need to make their evacuation decisions, mobilize support personnel, communicate evacuation decisions between affected communities and the State, and disseminate evacuation directives to the public.

The length of dissemination time is a function of established communication and decision-making procedures of the State and individual communities, and consequently can vary greatly by community. Because of this, the Study does not attempt to quantify this time for individual communities or the State. Consequently, hurricane evacuation decision-makers in Massachusetts must establish dissemination times appropriate for their areas in order to properly use the clearance times developed by this study. Failure to include dissemination time in the calculation of total evacuation time will underestimate the time it takes to ensure a safe and complete evacuation.

The Decision Arc Method presented in Chapter Eight explains a step-by-step hurricane evacuation decision-making procedure. This method uses evacuation time in conjunction with National Hurricane Center advisories to estimate when evacuation must begin in order to be completed prior to the arrival of hurricane gale force winds associated with the hurricane. The method is designed to help compensate for forecast errors by relating evacuation decisions to hurricane position.

MITIGATION

It is recommended that the communities in Dukes and Nantucket Counties continue to develop their hurricane preparedness plans to ensure safe evacuation from the islands prior to a hurricane threat for those who choose to leave the islands, and safe sheltering of those who choose to stay on-island. It is also recommended that the Massachusetts Emergency Management Agency continue to coordinate with the Massachusetts State Police to improve traffic flow at the Bourne and Sagamore rotaries. It was found in the Transportation Analysis that such measures could reduce roadway clearance times by up to 1½ hours.

CONCLUSIONS

The completion of this multi-year study does not conclude the Corps of Engineers or the FEMA's involvement in hurricane preparedness activities in southern Massachusetts. The effectiveness of this study depends upon continued hurricane preparedness training and public awareness at all levels. FEMA and the Massachusetts Emergency Management Agency will incorporate the results of this study into their ongoing program of improving hurricane emergency management in Massachusetts. The following key points are emphasized to facilitate incorporation of this study's results into existing State and local hurricane preparedness plans.

1. Results from the SLOSH model show that storm surge generation in Massachusetts is significantly influenced by a hurricane's intensity category and its forward speed. The Hazards Analysis shows that at most southern Massachusetts locations, surges which accompany fast moving Category 2 hurricanes (forward speeds greater than 40 mph) can generate surge levels close to or greater than the levels generated by more intense Category 3 or 4 hurricanes traveling at slower forward speeds (forward speeds of 20 mph or less). This phenomenon is caused by the increased wind stress on ocean water on the right side of the hurricane's eye from storms which travel at faster speeds. Consequently, it is important to understand that both the category and forward speed of an approaching hurricane are major factors in determining the storm's threat in terms of flood potential.

2. Errors in forecasting complicate hurricane evacuation decision-making, and it is important to recognize the forecasting capabilities and inherent limitations of hurricane forecasting by the National Weather Service. Even slight deviations in the forecasted

track of a hurricane might mean a large difference in landfall location. The average error in a 12 hour hurricane forecast is approximately 60 miles. To illustrate how deviations from the forecasted track complicate evacuation decision-making, consider a hurricane that is forecasted to make landfall at the Rhode Island/Massachusetts border in 12 hours time. If this storm were to actually landfall anywhere between the vicinity of East Lyme, Connecticut and Chatham, Massachusetts, the resulting error in forecasted landfall location would be no worse than average. Stated another way, suppose that a hurricane that is forecasted to make landfall along the coast of Rhode Island in 12 hours actually hits Cape Cod directly, then its associated track error would be within error ranges typically forecasted. It follows from these examples that Massachusetts is potentially vulnerable to every hurricane forecasted to reach New England.

3. The New Bedford Hurricane Barrier, located in Clark Cove in New Bedford and in New Bedford Harbor in the communities of New Bedford and Fairhaven, provides a high degree of tidal-flood protection to an area of about 1,400 acres of heavily developed industrial and commercial properties along the waterfront and the Acushnet River. A review of the storm surge data calculated by the SLOSH model indicates that peak surges generated from category 3 and 4 hurricanes, with forward speeds greater than 40 mph, may exceed the barrier's design elevation. Hurricanes that exceed the barrier's design height travel on a north-northwest to north-northeast track direction, and landfall at the critical location to produce the highest level of storm surge at New Bedford. It is also assumed that the hurricane landfalls coincident with high astronomical tide. It is extremely unlikely that all critical meteorological and hydrological conditions will occur simultaneously at New Bedford. However, it is important to understand the public's potential risk should a storm of this nature be forecasted. Section 2.5.7 of the Technical Data Report contains further discussion of surge heights at the New Bedford Hurricane Barrier.

4. Although behavior during a hurricane evacuation is difficult to predict, two overriding factors influence whether or not residents will evacuate: 1) the actions by local officials; and 2) the perceived degree of hazard at their location. The results of this study indicate that when officials take aggressive action to encourage people to leave their homes, evacuation rates increase by approximately 25 to 50 percent. It has also been found that the time at which people mobilize and evacuate is closely related to local officials' actions. During evacuation proceedings it is recommended that clear and consistent warnings are

broadcasted to the public at risk to supplement "door to door" warning efforts.

5. The Shelter Analysis determined that the expected shelter utilization is greater than the reported shelter capacity in several of the study communities. These communities are encouraged to continue to work to identify additional public shelters.

6. The study presents roadway clearance times for 18 hurricane evacuation scenarios, each varying by the intensity of the approaching hurricane, the response time of evacuees leaving their homes, and the background traffic condition at the start of the evacuation. Estimated roadway clearance times for Cape Cod were found to be longer than for other areas in coastal southern Massachusetts and also longer than the clearance times calculated for coastal communities in Connecticut and Rhode Island in prior Hurricane Evacuation studies.

Clearance times developed for this study do not apply to the communities in Dukes and Nantucket Counties. It is recommended those communities continue to develop their hurricane preparedness plans to ensure safe evacuation from the islands prior to a hurricane threat for those who choose to leave the islands, and safe sheltering of those who choose to stay on-island.

7. To ensure that suitable evacuation times are used in hurricane evacuation decision-making, it is important that State and local officials investigate existing communication and warning procedures and establish an appropriate amount of dissemination time. Dissemination time is a critical component of evacuation time. Failure to include this time as part of total evacuation time may substantially underestimate the time required to complete evacuations safely. It is recommended that officials refer to the Hurricane Bob Preparedness Assessment for Coastal Areas of Southern New England and New York, May 1993 for information that may be of assistance in quantifying dissemination time.

8. It is recommended that decision-makers use the Decision Arc Method outlined in Chapter Eight to assist in determining if, and when, a hurricane evacuation should be conducted. The method requires that decision-makers have access to the latest Tropical Cyclone Forecast/Advisory and Tropical Cyclone Probability Advisory issued by the National Hurricane Center.

9. It is recommended that the Massachusetts Emergency Management Agency continue to coordinate with the Massachusetts State Police to improve traffic flow at the Bourne and Sagamore rotaries. It was found in the Transportation Analysis that such measures could reduce roadway clearance times by up to 1½ hours.

TABLE OF CONTENTS

Chapter One: INTRODUCTION

Chapter Two: HAZARDS ANALYSIS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

Chapter Six: TRANSPORTATION ANALYSIS

Chapter Seven: EVACUATION TIMES

Chapter Eight: DECISION ANALYSIS

TABLE OF CONTENTS (Continued)

SOUTHERN MASSACHUSETTS HURRICANE EVACUATION STUDY COMPANION ATLASES

INUNDATION MAP ATLAS, December 1994

EVACUATION MAP ATLAS, April 1997

SOUTHERN MASSACHUSETTS HURRICANE EVACUATION STUDY APPENDICES

APPENDIX A: Storm Surge Atlas for the Narragansett Bay, RI and Buzzards Bay, MA Area

APPENDIX B: Storm Surge Atlas for the Boston Bay, MA Area

APPENDIX C: Behavioral Analysis Support Documentation

APPENDIX D: Transportation Analysis Support Documentation

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

Preface

In 1938, the Great New England Hurricane was the only hurricane to threaten the east coast of the United States. It developed from a tropical storm originating off the coast of southwest Africa near the Cape Verde Islands, and within days of its formation, reached hurricane strength and headed west toward the north Atlantic coast. As it approached the Virgin Islands, the hurricane quickly curved northward on a track that paralleled the coast. By 7:00 a.m. on September 21, the eye passed 150 miles off Cape Hatteras. High pressure areas on either side of the system funneled it on a northerly track directly to New England.[1] Because of the storm, many marine vessels along the Atlantic seaboard safeguarded their ships far out to sea or secured them along inner harbors. The absence of weather reports from these ships, and the primitive weather observation equipment of that time, resulted in sparse weather surveillance and forecasts with little detail or confidence.

By 2:30 in the afternoon, Weather Bureau officials in Boston realized the system had unexpectedly accelerated to more than 50 mph, and had traveled nearly 600 miles in twelve hours. Officials aired warnings that a tropical hurricane was in the vicinity of New York and was expected to move over New England's inland within two hours time. The hurricane, accompanied by sustained winds in excess of ninety-five mph, made landfall at New Haven, Connecticut at 3:30 p.m. coincident with normal high tides. Many New England residents never received warnings, while others did not react to the sketchy forecasts until it was too late.

The hurricane caused extensive damage from surge, winds, and freshwater flooding. Cottages and ocean front homes were washed more than a half mile from the shore, and recreational boats and shipping fleets were scattered along the coastline for miles. Hurricane winds destroyed entire forests. Heavy rainfall that was brought by the storm, coupled with rains four days before the storm, caused severe freshwater flooding conditions in many inland areas. Numerous New England cities and towns experienced some of the highest flood levels ever reported. In total, the storm gave rise to more than

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[1]Hale, Cushman & Flint, New England Hurricane, Federal Writers' Project, Boston, MA 1938.

$400,000,000 in damages (in 1995 dollars, the estimated damages translate to $6.8 billion). An estimated 682 New England deaths were directly attributed to the Hurricane of 1938.[2]

New England has historically faced about five to ten major hurricanes per century. Coastal communities in southern Massachusetts are vulnerable to all hurricanes forecasted to track towards New England. Certain regional factors increase the potential for damage from surge flooding in southern Massachusetts. Such factors include the south-facing shoreline of many communities, the surge-funneling characteristics of Buzzard's Bay, and the large tide range in many areas. The Commonwealth's vulnerability is further complicated by its growing population and increased development in coastal areas.

In southern New England, the Hurricane of 1938 has been established by many as the benchmark storm of record by which all other hurricanes are compared. In fact, locations approximately 20 to 30 miles east of the point of landfall probably experienced storm surges that approach the worst case conditions for their areas. However, for most other locations, surges would have been higher had the storm made landfall at a different location.

Today, hurricane preparedness plans in many coastal communities use historical flood levels as a basis for identifying homes and businesses that may require evacuation. Historic flood levels can assist in public education and help to identify land areas that will initially flood before peak surge arrives. However, hurricane preparedness plans based only on historical data may compromise the public's safety by underestimating potential impacts. For this reason, hurricane preparedness plans must consider worst case surge levels that may occur at all coastal locations from all reasonably likely combinations of hurricane conditions.

It is now possible to forecast the intensity and forward speed of an approaching hurricane and to broadcast that information to officials and the public in a relatively short amount of time. However, it remains difficult to forecast the landfall location, and there are no anticipated advances in hurricane track forecasting that would allow the precise

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[2]Federal Emergency Management Agency, Interagency Hazard Mitigation Report - Hurricane Bob, 1992.

determination of specific areas requiring hurricane evacuation. Consequently, to ensure the safety of all threatened areas, hurricane evacuation decisions consider large shoreline areas and involve the displacement of many people. The decision of public officials to order or recommend a hurricane evacuation is not an easy one.

It is anticipated that hurricane evacuations conducted in southern Massachusetts will take many hours to complete. In fact, in order for an evacuation to be completed before the onset of dangerous winds, people must begin seeking safe refuge while a hurricane is still hundreds of miles away. Evacuees will compete for roadway space with others making last minute shopping trips, and with tens of thousands of people leaving work. If evacuations are not conducted in advance, people could be left stranded on highways or in surge vulnerable homes as a hurricane strikes.

Officials of some communities can reasonably estimate time required to evacuate residents to public shelters located in their own communities. It is more difficult, however, to estimate how long it will take to clear vehicles off all roadways if evacuations are conducted in several adjacent communities. The analyses presented in this study are intended to quantify this time.

State and local officials must have reliable information on potential hurricane surge areas (based on the intensity and forward speed of the hurricane), accurate estimates of the population at risk and the number that can be expected to evacuate, public shelter capacities and locations, and estimates of the amount of time needed to complete an evacuation. The fiscal and staffing limitations of most State and local emergency management agencies hinders the development of this information. To assist State and local governments, the Federal Emergency Management Agency (FEMA) and the US Army Corps of Engineers, in cooperation with the National Oceanic and Atmospheric Administration, have joined the Massachusetts Emergency Management Agency in conducting the Southern Massachusetts Hurricane Evacuation Study.

Chapter One

INTRODUCTION

1.1 PURPOSE

The purpose of this study is to provide the Massachusetts Emergency Management Agency and the coastal communities in southern Massachusetts, including Cape Cod and the Islands, with data quantifying the major factors involved in hurricane evacuation decision-making. The technical data presented in this report, and its companion atlases, is not intended to replace hurricane preparedness plans currently in use by the Commonwealth or the communities. Rather, the information developed from this report will provide a framework within which State and local emergency management officials can update or revise existing hurricane evacuation plans, and from which integrated State and community hurricane response procedures can be developed to improve public preparedness and response during future hurricane threats.

1.2 AUTHORITY

This study was conducted by the Federal Emergency Management Agency (FEMA) and the US Army Corps of Engineers in cooperation with the National Oceanic and Atmospheric Administration (NOAA) for the Massachusetts Emergency Management Agency. Funding was provided by FEMA under the Disaster Relief Act of 1974 (Public Law 93-288); and by the US Army Corps of Engineers under the Flood Plain Management Services program, Section 206, of the Flood Control Act of 1960 (Public Law 86-645). These laws authorized the allocation of resources for planning activities related to hurricane preparedness.

1.3 STUDY AREA DESCRIPTION

1.3.1 Geography

The study area, shown in Figure 1.1, consists of 37 coastal communities in Barnstable, Bristol, Dukes, Nantucket, and Plymouth counties. The southern Massachusetts study area focuses on immediate coastal communities only and does not provide specific information for the entire counties for two reasons. First, the study's main objective is to develop data to help prevent the loss of life caused by hurricane surge flooding. Therefore, only those communities directly exposed to open coasts, bay inlets,

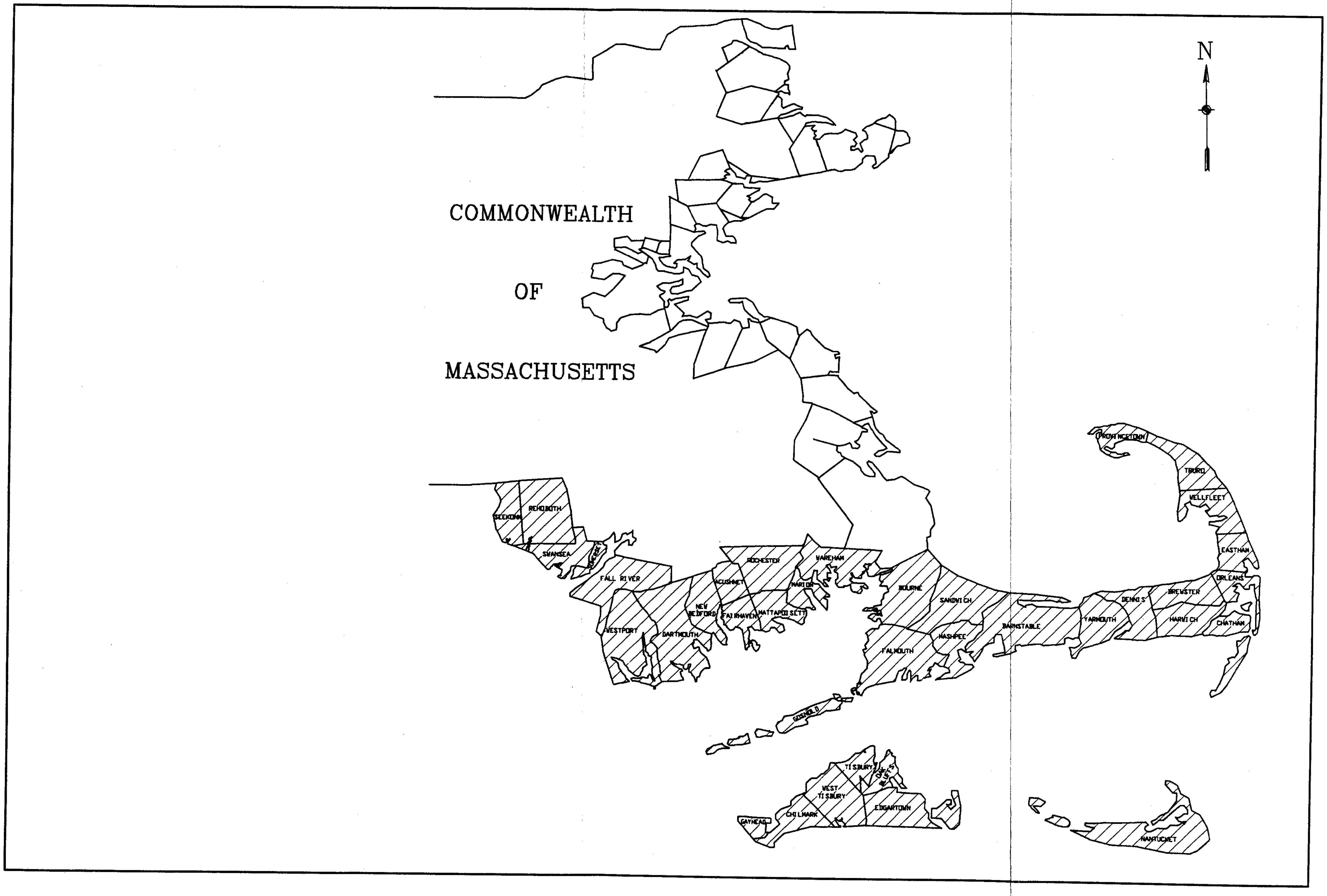

Figure 1.1 Study Area

or located along rivers subject to tidal influences are included in the study area. Second, the local government structure in Massachusetts is based on the political boundaries of municipalities rather than county boundaries. Consequently, emergency management functions, including hurricane preparedness, evacuation decision making, response, and recovery are the responsibility of each individual city and town.

The Commonwealth of Massachusetts is the sixth smallest state in the Nation geographically with a total land area of 7,838 square miles. The 1990 population was slightly more than six million. Approximately one-tenth of the Commonwealth's population is concentrated in the 37 coastal communities included in this study.

Table 1.1 shows the population change in the study communities for the period 1970 through 1990. The permanent population of the 37 study communities has increased approximately 33%, while the state-wide population has increased approximately 6%. Three study communities have experienced greater than 200% growth in the permanent population: Mashpee, Brewster, and West Tisbury. Nine additional communities have experienced greater than 100% growth in the permanent population: Sandwich, Dartmouth, Rochester, Eastham, Dennis, Edgartown, Barnstable, Oak Bluffs, and Harwich. Four of the study communities have experienced a slight decline in population: Fall River, Somerset, New Bedford, and Fairhaven.

The influx of seasonal residents to summer homes increases the total summer population dramatically in some areas. The total summer population of Martha's Vineyard is more than 7 times the permanent population, and the total summer population of Nantucket is more than four times the permanent population. For Cape Cod as a whole, the total summer population is about 2 ½ times the permanent population, while the population of the Town of Wareham approximately doubles in the summer. The seasonal population of the other study communities is relatively small.

TABLE 1.1

CHANGE IN POPULATION WITHIN THE STUDY COMMUNITIES

1970-1990

COMMUNITY	POPULATION 1970	1990	% CHANGE
Acushnet	7,767	9,554	23%
Barnstable	19,842	40,949	106%
Bourne	12,636	16,064	27%
Brewster	1,790	8,440	372%
Chatham	4,554	6,579	44%
Chilmark	340	650	91%
Dartmouth	10,800	27,244	152%
Dennis	6,454	13,864	115%
Eastham	2,043	4,462	118%
Edgartown	1,481	3,062	107%
Fairhaven	16,332	16,132	-1%
Fall River	96,090	92,703	-4%
Falmouth	15,942	27,960	75%
Gay Head	118	201	70%
Gosnold	83	98	18%
Harwich	5,092	10,275	102%
Marion	3,466	4,496	30%
Mashpee	1,268	7,884	522%
Mattappoisett	4,503	5,850	30%
Nantucket	3,774	6,012	59%
New Bedford	101,777	99,922	-2%
Oak Bluffs	1,385	2,804	102%
Orleans	3,055	5,838	91%
Provincetown	2,911	3,561	22%
Rehoboth	4,512	8,656	92%
Rochester	1,770	3,921	122%
Sandwich	5,239	15,489	196%
Seekonk	11,116	13,046	17%
Somerset	18,008	17,655	-2%
Swansea	12,640	15,411	22%
Tisbury	2,257	3,120	38%
Truro	1,234	1,573	27%
Wareham	11,492	19,232	67%
Wellfleet	1,743	2,493	43%
West Tisbury	453	1,704	276%
Westport	9,791	13,852	41%
Yarmouth	12,033	21,174	76%
TOTAL	417,761	553,920	33%
STATE	5,689,170	6,016,425	6%

1.3.2 Topography and Landforms

The coast of southern Massachusetts is irregular and marked by many headlands, sandy beaches, inlets, and rocky shores. In the Buzzards Bay area, swampy lowlands are typical features of the region. The lowland topography is exceptionally favorable for cranberry bogs, which are located throughout the northeastern Buzzards Bay communities. Although the straight-line distance along the shore is approximately 32 miles, the actual shoreline is about 210 miles long. Bays, coves, and promontories create an extremely irregular coastal outline and offer a few sheltered anchorages and harbors. A major Massachusetts state beach, at Horseneck Point in Westport, is one of the most actively used coastal facilities between Providence and Cape Cod. While many of the headlands are either bedrock outcrops or gravel bluffs, there are many pockets of broad tidal marshes and shallow, sandy coves which make up the Buzzards Bay coastline.

Cape Cod and the Islands were formed by glacial moraines and till. Of the 584 miles of shoreline on Cape Cod and the Islands, 407 miles are classified as sandy beaches. Beaches which have been developed with recreational facilities total about148 miles, a fact which explains the region's popularity with vacationers from all parts of the country. Coastal erosion has always been an active process in creating and modifying the eastern beaches on the outer Cape. Longshore drift carries the sand north and south to be deposited at Provincetown or on Monomoy Island. A significant portion of the remaining coastal features are made up of towering bluffs, rolling sand dunes, tidal marshes, and shallow embayments.

The largest man-made protective structure in the study area is the New Bedford Hurricane Barrier, built by the Army Corps of Engineers in 1966. The Barrier is located in Clark Cove and New Bedford Harbor in the communities of New Bedford and Fairhaven, Massachusetts. The project affords a high degree of tidal-flood protection to an area of about 1,400 acres of heavily developed industrial and commercial properties along the waterfront and the Acushnet River.

1.3.3 Tide Ranges

Table 1.2 lists the approximate mean tide ranges for each study community. The mean tide range is the difference between mean low water and mean high water. Tide elevations vary by location along the coast, even within a community. Therefore, representative tide elevations are listed in **Table 1.2** to allow comparison between communities. For more detailed tidal information, refer to NOAA's 1997 Tide Tables and the Corps of Engineers Tidal Flood Profiles for the New England Coastline, September 1988. The outer Cape has the greatest tide ranges within the study area. In each outer Cape community, the tide range on Cape Cod Bay is greater than along the open ocean. Tide ranges within Buzzards Bay are also higher than for most coastal locations along the open ocean, excluding the outer Cape.

TABLE 1.2
APPROXIMATE TIDE RANGES FOR THE STUDY COMMUNITIES [1]

COMMUNITY	Mean High Tide Elevation (Feet NGVD)[2,3]	Mean Low Tide Elevation (Feet NGVD)[2,3]	Mean Tide Range (Feet)
Acushnet	2.4	-1.2	3.6
Barnstable - Ocean side	1.8	-0.9	2.7
Barnstable - Bay side	5.1	-4.4	9.5
Bourne	2.8	-1.3	4.1
Brewster	5.3	-4.5	9.8
Chatham	2.2	-1.6	3.8
Chilmark	Note 4	Note 4	2.9 [5]
Dartmouth	2.3	-1.2	3.5
Dennis - Ocean coast	1.9	-1.2	3.1
Dennis - Bay coast	5.2	-4.4	9.6
Eastham - Ocean coast	Note 4	Note 4	6.0 [5]
Eastham - Bay coast	5.4	-4.5	9.9
Edgartown	Note 4	Note 4	1.9 [5]
Fairhaven	2.4	-1.2	3.6
Fall River	2.8	-1.3	4.1
Falmouth - Bay coast	2.6	-1.3	3.9
Falmouth - Ocean coast	1.2	-0.1	1.3
Gay Head	Note 4	Note 4	2.9 [5]
Gosnold	1.7	-0.5	2.2
Harwich	2.1	-0.5	2.6
Marion	2.7	-1.3	4.0

TABLE 1.2 (continued)
APPROXIMATE TIDE RANGES FOR THE STUDY COMMUNITIES [1]

COMMUNITY	Mean High Tide Elevation (Feet NGVD)[2,3]	Mean Low Tide Elevation (Feet NGVD)[2,3]	Mean Tide Range (Feet)
Mashpee	1.3	-0.3	1.6
Mattappoisett	2.6	-1.3	3.9
Nantucket	Note 4	Note 4	1.2 to 3.1 [5]
New Bedford	2.4	-1.2	3.6
Oak Bluffs	Note 4	Note 4	1.7 [5]
Orleans - Ocean coast	Note 4	Note 4	6.2 [5]
Orleans - Bay coast	5.3	-4.5	9.8
Provincetown	5.1	-3.9	9.0
Rehoboth	Note 6	Note 6	Note 6
Rochester	Note 6	Note 6	Note 6
Sandwich	4.7	-4.2	8.9
Seekonk	Note 6	Note 6	Note 6
Somerset	3.0	-1.3	4.3
Swansea	2.7	-1.3	4.0
Tisbury	1.5	-0.3	1.8
Truro - Ocean coast	3.2	-3.6	6.8
Truro - Bay coast	5.3	-4.2	9.5
Wareham	2.8	-1.3	4.1
Wellfleet - Ocean coast	Note 4	Note 4	6.8 [5]
Wellfleet - Bay coast	5.4	-4.4	9.8
West Tisbury	1.5	-0.3	1.8
Westport	2.2	-1.1	3.3
Yarmouth - Ocean coast	1.8	-1.1	2.9
Yarmouth - Bay coast	5.2	-4.3	9.5

[1] Tide elevations vary by location along the coast, even within a community. Representative tide elevations were selected for Table 1.2.
[2] Elevation in feet above/below National Geodetic Vertical Datum of 1929.
[3] Corps of Engineers Tidal Flood Profiles for the New England Coastline, September 1988.
[4] This information was not listed in the publications referenced in Notes 3 and 5.
[5] NOAA 1997 Tide Tables.
[6] These communities are exposed to hurricane surge which moves up nearby rivers. There is no information in the referenced publications on tide ranges in the rivers in these communities.

1.4 HISTORICAL HURRICANE ACTIVITY

1.4.1 General

Hurricanes are a classification of tropical cyclones which are defined by the National Weather Service as non-frontal, low pressure synoptic scale (large scale) systems that develop over tropical or subtropical water and have definite organized circulations. Tropical cyclones are categorized based on the speed of the sustained (1-minute average) surface wind near the center of the storm. These categories are: Tropical Depression (winds less than 33 knots), Tropical Storm (winds 34 to 63 knots inclusive) and Hurricane (winds greater than 64 knots).

The geographic areas affected by tropical cyclones are called tropical cyclone basins. The Atlantic tropical cyclone basin is one of six in the world and includes much of the North Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico. The official Atlantic hurricane season begins on June 1 and extends through November 30 of each year, but occasionally tropical cyclones occur outside this period. Early season tropical cyclones are almost exclusively confined to the western Caribbean and the Gulf of Mexico. However, by the end of June or early July, the area of formation gradually shifts eastward. By late July the frequency of storms gradually increases, and the area of formation shifts still farther eastward.

By late August, tropical cyclones form over a broad area that extends eastward to near the Cape Verde Islands located off the coast of Africa. The period from about August 20 through about September 15 encompasses the maximum of the Cape Verde type storms, many of which travel across the entire Atlantic Ocean. After mid-September, the frequency begins to decline and the formative area retreats westward. By early October, the area is generally confined to the western Caribbean. In November, the frequency of tropical cyclone occurrences declines still further.

1.4.2 Atlantic Tropical Cyclone Basin

Records of tropical cyclone occurrences in the Atlantic Tropical Cyclone Basin since 1871 have been compiled by the National Climate Center in cooperation with the National Hurricane Center. Although other researchers have compiled fragmentary data concerning tropical cyclones within the Atlantic tropical cyclone basin dating back as early as the late fifteenth century, the years from 1871 to the present represent the complete period of the development of meteorology and organized weather services in the United States. For the 122-year period from 1871 through 1996, nearly 1000 tropical cyclones have occurred within the Atlantic Tropical Cyclone Basin. The National Hurricane Center maintains detailed computer files of Atlantic tropical cyclone tracks back to 1886. Of the 852 known Atlantic tropical cyclones of at least tropical storm intensity occurring during the period 1886 through 1986, 499 reached hurricane intensity. Figure 1.2 provides a histogram of the total number of tropical storms and hurricanes observed for a 100-year period from May 1, 1886 through December 31, 1986.

1.4.3 Coastal New England

Between 1886 and 1996, 20 tropical cyclones of hurricane intensity have passed within 125 statute miles of Boston, Massachusetts, for an average of one hurricane within every 5.5 years. This means that for locations within a 125 statute mile radius of Boston, on average, a hurricane can statistically be expected to pass every 5.5 years. **Table 1.3** lists the names, date of occurrence, and meteorological characteristics of each hurricane. The tracks of the 20 hurricanes are displayed as follows: storms which entered the region on a northerly track are shown in Figure 1.3, storms which entered the region on a north-northeasterly track are shown in Figure 1.4, and storms which entered the region on a northeasterly track are shown in Figure 1.5.

Massachusetts, as with other New England states, is particularly vulnerable to hurricanes. One reason is due to the geography of southern New England in relation to the Atlantic seaboard. Historically, most hurricanes which have struck the New England region re-curved northward on tracks which paralleled the eastern seaboard maintaining a slight north-northeast track direction. The fact that Connecticut, Rhode Island, and Massachusetts geographically project easterly into the Atlantic and have southern exposed shorelines place them in direct line of any storm which tracks in this manner. Therefore, even though New England is a relatively far distance from the tropics, its susceptibility to hurricane strikes can statistically be greater than other states closer to the tropics.

Another explanation giving evidence to New England's unique vulnerability to hurricanes is the fact that hurricanes which eventually strike the region undergo significant increases in forward speed. Historically, it can be shown that hurricanes tend to lose their

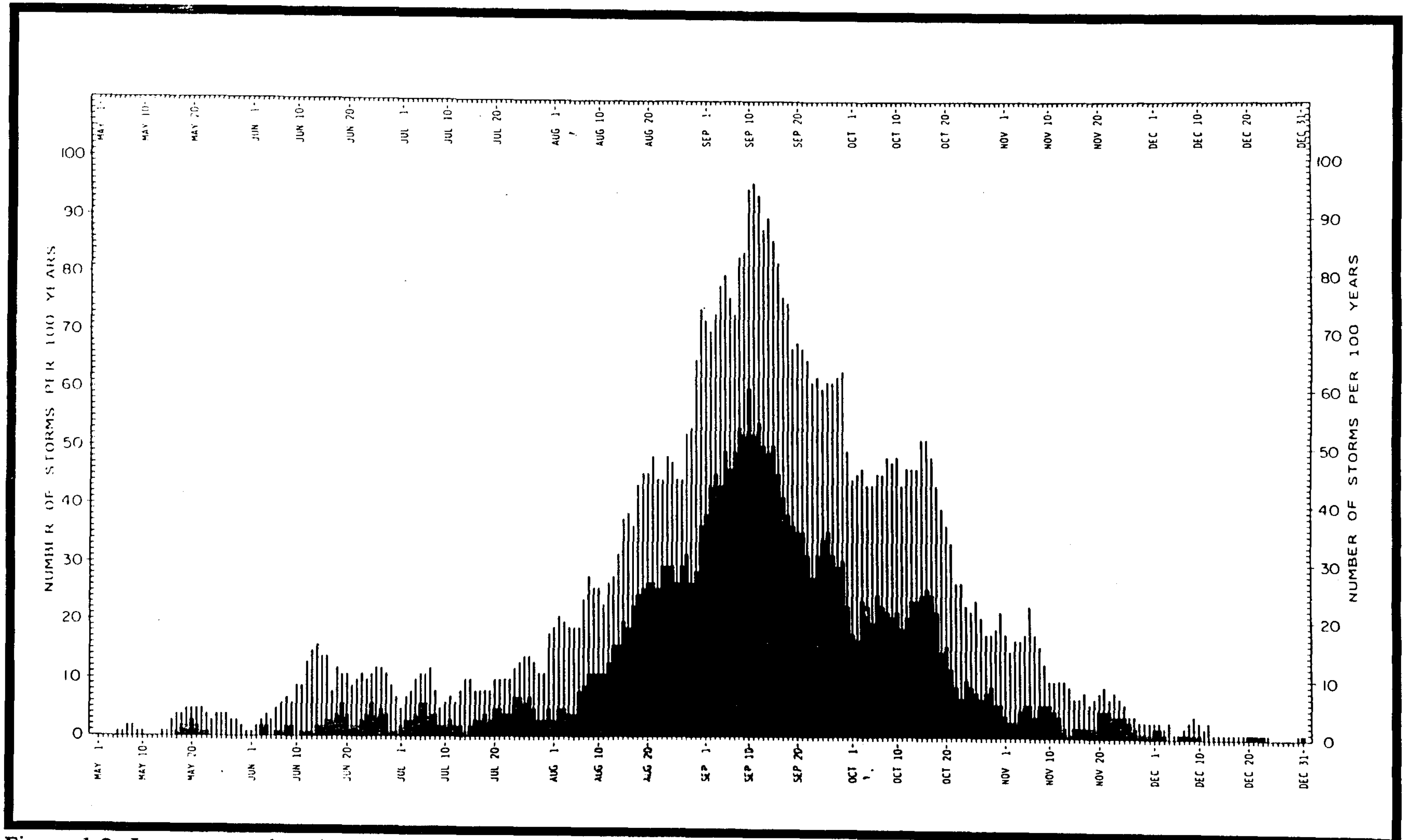

Figure 1.2 Intra-seasonal variations in the 100-year frequency of tropical cyclone occurrence. Lower bar is for hurricanes and upper bar is for hurricanes and tropical storms combined. Summary is based on period of record, 1886-1986. Source: NOAA

strength and accelerate in a forward motion after pasting the outer banks of Cape Hatteras, North Carolina. The increase in forward speed that usually occurs simultaneously as the hurricane weakens with further northward movement can often compensate for any discounting in hurricane intensity. Consequently, surge flooding, wave effects, and wind speeds accompanying a faster moving, weaker hurricane may exceed conditions caused by more intense hurricanes. This means that for some locations, depending on the meteorology of the storm, the affects from a Category 2 hurricane traveling at 60 miles per hour (mph) might be worse than that from a Category 4 hurricane moving at 20 mph.

TABLE 1.3
HURRICANES WITHIN 125 STATUTE MILES OF BOSTON, MASSACHUSETTS 1886-1996

		AT CLOSEST POINT OF APPROACH		
DATE OF STORM	STORM NAME	MAXIMUM WIND (MPH)	RANGE (MILES)	FORWARD SPEED (MPH)
1888 NOV 27[1]	Unnamed	98	76	11
1891 OCT 14	Unnamed	98	63	15
1893 AUG 24	Unnamed	90	81	25
1893 AUG 29	Unnamed	72	85	37
1896 SEP 10	Unnamed	104	75	10
1904 SEP 15	Unnamed	75	9	52
1908 AUG 1	Unnamed	98	100	20
1916 JUL 21	Unnamed	84	22	18
1924 AUG 26	Unnamed	104	62	41
1927 AUG 24	Unnamed	104	63	48
1936 SEP 19	Unnamed	92	37	32
1938 SEP 21	Unnamed	90	70	51
1940 SEP 2	Unnamed	80	81	26
1944 SEP 15	Unnamed	77	24	29
1954 AUG 31	Carol	92	41	35
1954 SEP 11	Edna	92	25	46
1960 SEP 12	Donna	95	33	39
1961 SEP 26	Ester	122	38	6
1962 AUG 29	Alma	95	74	14
1985 SEP 27	Gloria	86	62	45
1991 AUG 19	Bob	100	7	32

Source: National Hurricane Center.

[1] This storm may have been a hybrid with both tropical and extratropical characteristics.

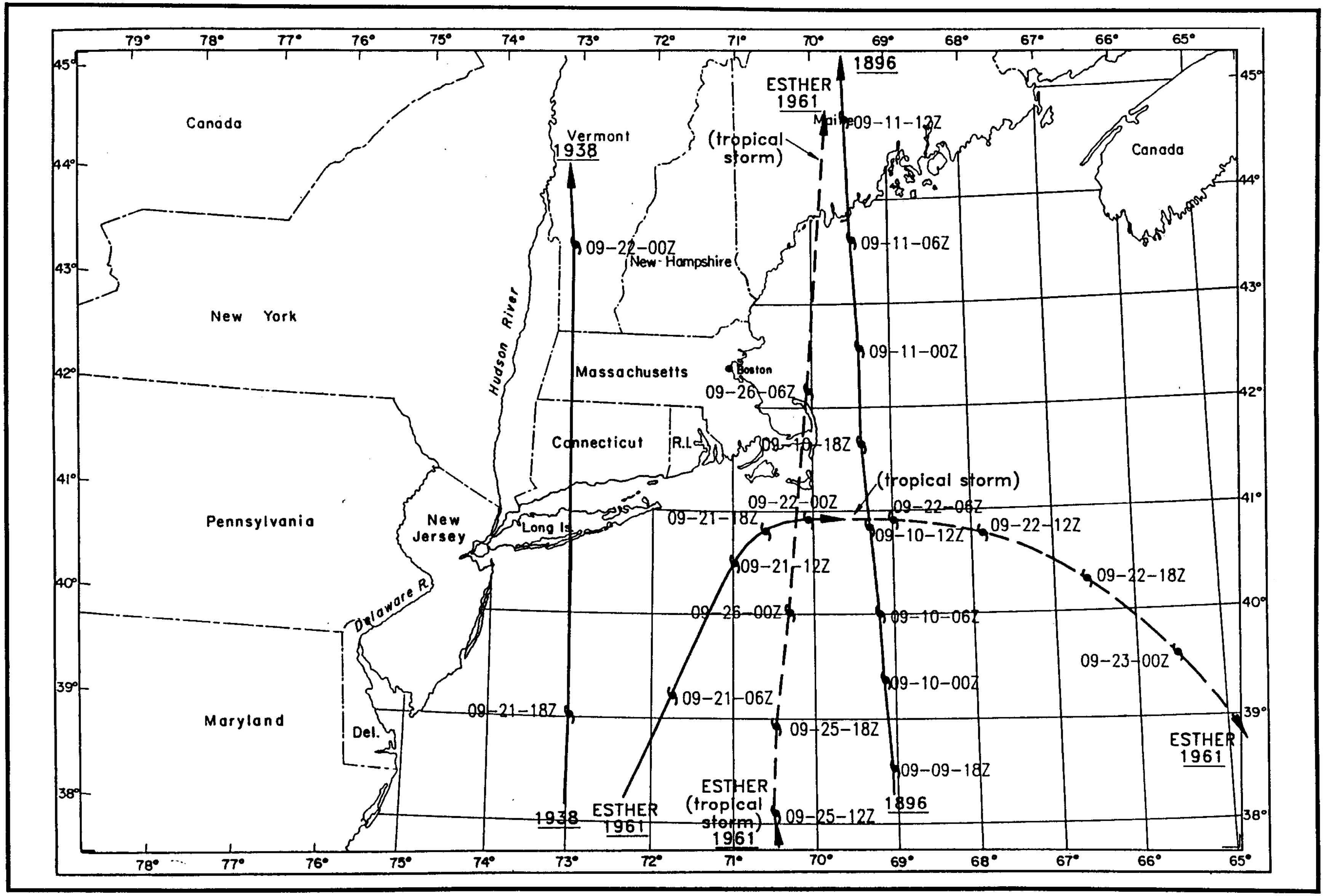

Figure 1.3 Northbound hurricanes and tropical storms passing within 125 statute miles of Boston, Massachusetts from 1886-1996.
Source: NHC

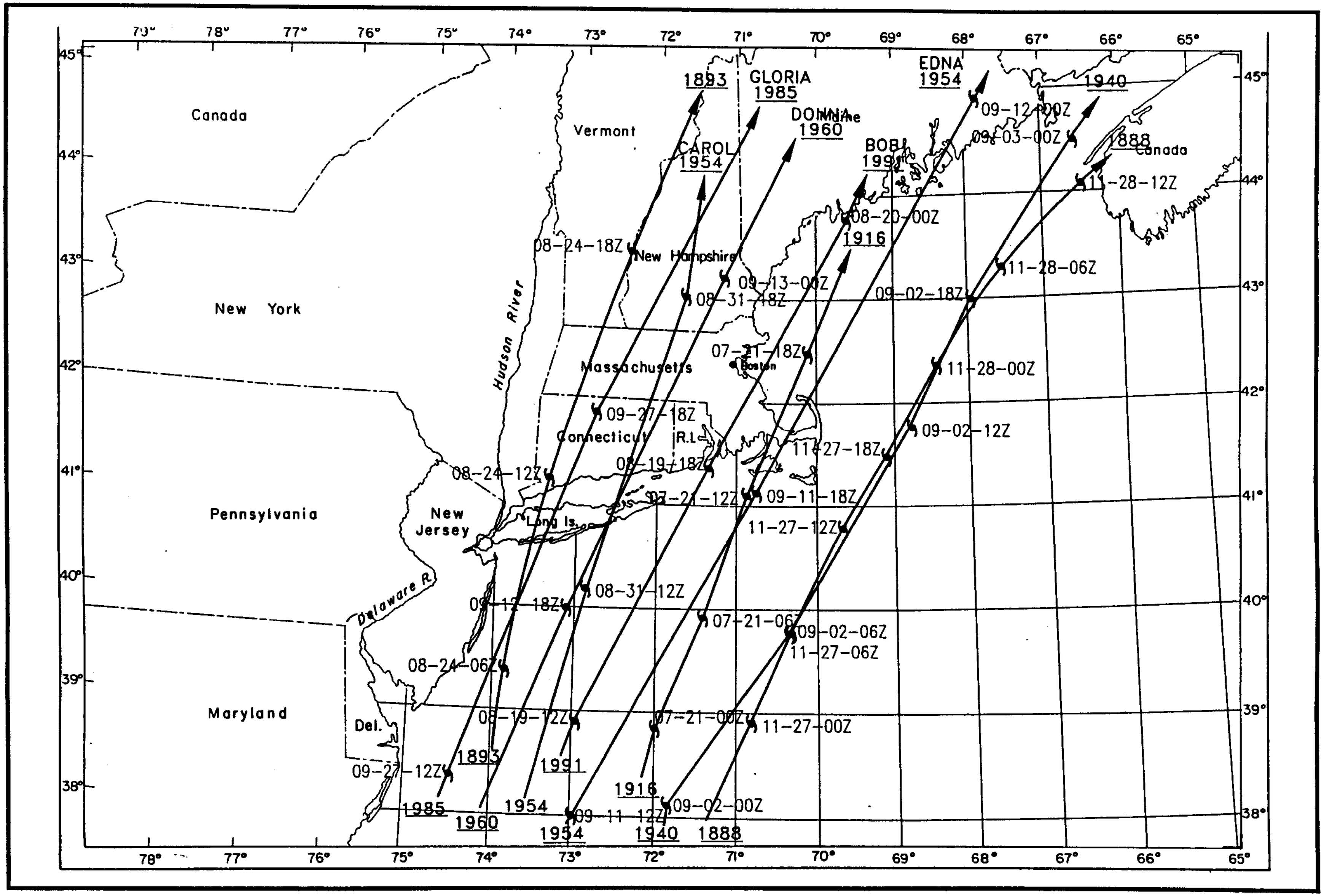

Figure 1.4 North-northeast moving hurricanes and tropical storms passing within 125 statute miles of Boston, Massachusetts from 1886-1996. Source: NHC

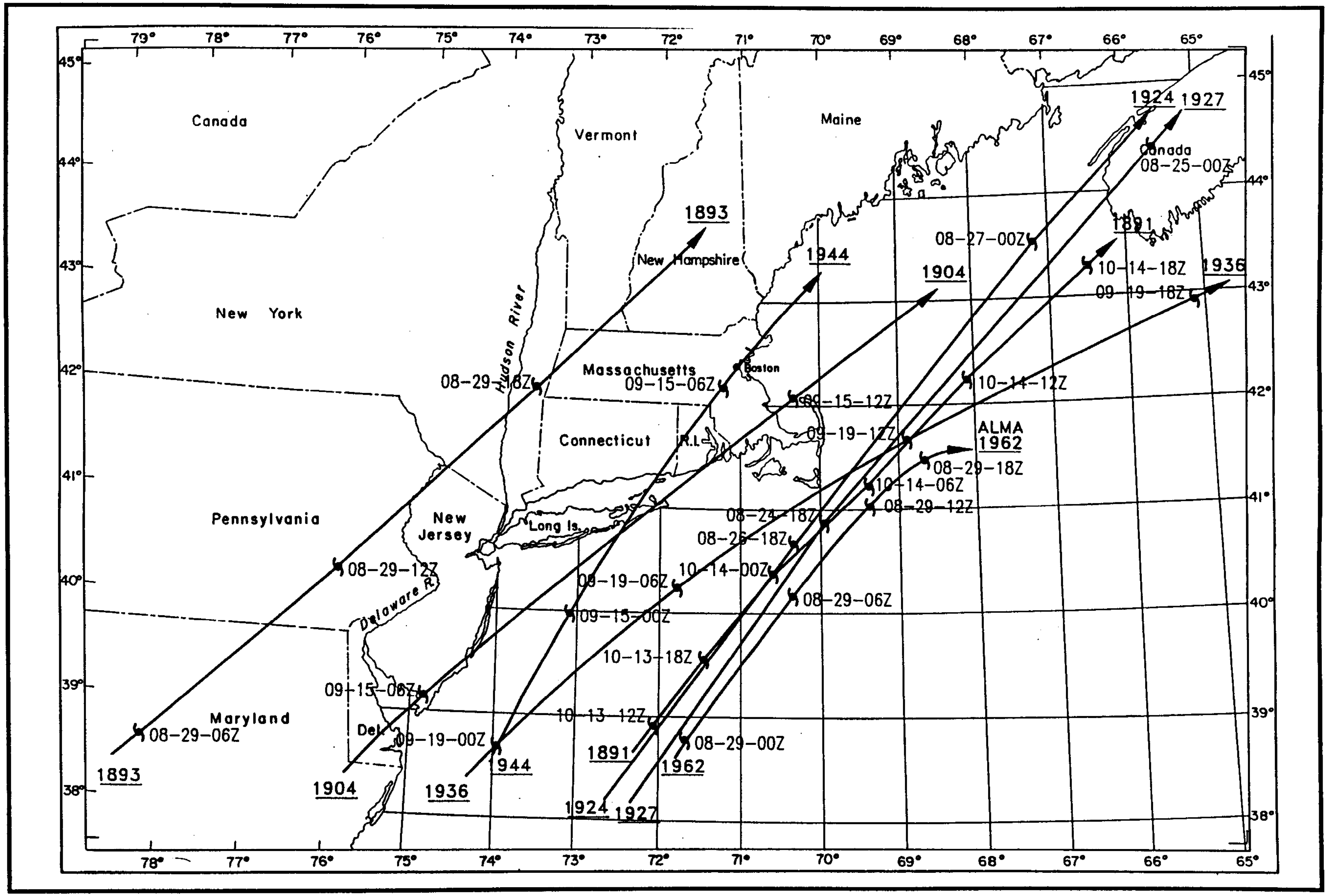

Figure 1.5 Northeast moving hurricanes and tropical storms passing within 125 statute miles of Boston, Massachusetts from 1886-1996. Source: NHC

The vulnerability of Southern Massachusetts to hurricane surges is further increased by the presence of Buzzard's Bay. The configuration of the bay can exhibit a funneling phenomenon on tidal surges. Ocean waters entering Buzzards Bay become more restricted causing higher flood levels with continued movement into the upper reaches of the bay. The funneled ocean waters along the shores of Buzzards Bay's northern most points tend to result in higher storm surge elevations causing a greater amount of coastal and tidal riverine flooding.

1.5 THE SAFFIR/SIMPSON SCALE

The National Hurricane Center adopted the Saffir/Simpson Hurricane Scale to categorize hurricanes based on their intensity, and to relate this intensity to damage potential. The Scale uses the sustained surface winds (1 minute average) near the center of the system to classify hurricanes into one of five categories. The Saffir/Simpson Hurricane Scale assumes an average, uniform coastline for the continental United States and was intended as a general guide for use by public safety officials during hurricane emergencies. Surge values greater than or less than the approximate ranges specified by the scale may occur due to effects of varying localized bathymetry, coastline configuration, astronomical tides, barriers, or other factors that may influence surge generation from a single event. A complete version of the scale is provided below.

CATEGORY 1: Winds of 74 to 95 miles per hour. Damage primarily to shrubbery, trees, foliage, and unanchored mobile homes. No real wind damage to other structures. Some damage to poorly constructed signs. Storm surge possibly 4 to 5 feet above normal. Low-lying coastal roads inundated, minor pier damage, some small craft in exposed anchorages torn from moorings.

CATEGORY 2: Winds of 96 to 110 miles per hour. Considerable damage to shrubbery and tree foliage; some trees blown down. Major damage to exposed mobile homes. Extensive damage to poorly constructed signs. Some damage to roofing materials of buildings; some window and door damage. No major wind damage to buildings. Storm surge possibly 6 to 8 feet above normal. Coastal roads and low-lying escape routes inland cut by rising water 2 to 4 hours before arrival of hurricane center. Considerable damage to piers. Marinas flooded. Small craft in unprotected anchorages torn from moorings. Evacuation of some shoreline residences and low-lying inland areas required.

CATEGORY 3: Winds of 111 to 130 miles per hour. Foliage torn from trees; large trees blown down. Practically all poorly constructed signs blown down. Some damage to roofing materials of buildings; some window and door damage. Some structural damage to small buildings. Mobile homes destroyed. Storm surge possibly 9 to 12 feet above normal. Serious flooding at coast and many smaller structures near coast destroyed; larger structures near coast damaged by battering waves and floating debris. Low-lying escape routes inland cut by rising water 3 to 5 hours before hurricane center arrives.

CATEGORY 4: Winds of 131 to 155 miles per hour. Shrubs and trees blown down; all signs down. Extensive damage to roofing materials, windows and doors. Complete failure of roofs on may small residences. Complete destruction of mobile homes. Storm surge possibly 13 to 18 feet above normal. Major damage to lower floors of structures near shore due to flooding and battering by waves and floating debris. Low-lying escape routes inland cut by rising water 3 to 5 hours before hurricane center arrives. Major erosion of beaches.

CATEGORY 5: Winds greater than 155 miles per hour. Shrubs and trees blown down; considerable damage to roofs of buildings; all signs down. Very severe and extensive damage to windows and doors. Complete failure of roofs on many residences and industrial buildings. Extensive shattering of glass in windows and doors. Some complete building failures. Small buildings overturned or blown away. Complete destruction of mobile homes. Storm surge possibly greater than 18 feet above normal. Major damage to lower floors of all structures less than 15 feet above sea level. Low-lying escape routes inland cut by rising water 3 to 5 hours before hurricane center arrives.

The National Hurricane Center has added a range of central barometric pressures associated with each category of hurricane described by the Saffir/Simpson scale. A condensed version of this scale, including the barometric pressure ranges by category, is shown in **Table 1.4**.

TABLE 1.4
SAFFIR/SIMPSON HURRICANE SCALE WITH CENTRAL BAROMETRIC PRESSURE RANGES

	CENTRAL PRESSURE		WIND SPEED		SURGE	DAMAGE
CATEGORY	MILLIBARS	INCHES	MPH	KNOTS	FEET	POTENTIAL
1	>980	>28.94	74-95	64-83	4-5	Minimal
2	965-979	28.5-28.9	96-110	84-96	6-8	Moderate
3	945-964	27.5-28.5	111-130	97-113	9-12	Extensive
4	920-944	27.2-27.9	131-155	114-135	13-18	Extreme
5	<920	<27.2	>155	>135	>18	Catastrophic

1.6 STUDY ANALYSES

The Southern Massachusetts Hurricane Evacuation Study consists of several related analyses. The analyses develop technical data concerning hurricane hazards, vulnerability of the population, public response to evacuation advisories, timing of evacuations, and sheltering needs for various hurricane threat situations. The major analyses are discussed in the following paragraphs.

1.6.1 Hazards Analysis (Chapter Two)

The Hazards Analysis determines the timing and sequence of wind and hurricane surge hazards that can be expected for hurricanes of various categories, tracks, and forward speeds impacting the study area. The Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model was used to develop the data. The model does not provide information regarding rainfall amounts or interior freshwater flooding, nor does this study attempt to determine freshwater flood elevations associated with hurricanes. It is assumed that local governments will use the National Flood Insurance Rate Maps prepared in conjunction with the National Flood Insurance Program to conduct evacuation planning for non-tidal areas.

1.6.2 Vulnerability Analysis (Chapter Three)

Utilizing the results of the Hazards Analysis, the Vulnerability Analysis identifies land areas within the study area which can potentially become inundated from hurricanes of different intensity. A companion atlas, entitled the Southern Massachusetts Hurricane Evacuation Study, Inundation Map Atlas, December 1994, illustrates the potential inundation areas for each study area community. Inundation information and 1990 census data were used to derive appropriate evacuation zones, from which estimates of the total population vulnerable to hurricane surge were made. A second companion atlas, entitled the Southern Massachusetts Evacuation Study, Evacuation Map Atlas, April 1997, presents these evacuation zones and includes the names and map locations of public shelters, medical/institutional facilities, and mobile home/trailer parks and campgrounds.

1.6.3 Behavioral Analysis (Chapter Four)

The Behavioral Analysis determines the expected response of the threatened population to hurricanes. Estimates are made regarding the percentage of the population that can be expected to evacuate, the amount of time it takes evacuees to mobilize to leave their homes and enter onto the roadway system, the expected number of persons per evacuating vehicle, and the estimated shelter utilization. The behavioral data was developed through telephone sample surveys of the public, interviews with local officials, information from other hurricane evacuation studies, and data obtained from post hurricane assessments. The behavioral analysis was conducted as part of an analysis completed for eight Middle Atlantic and New England states in support of joint Corps of Engineers, FEMA, and NWS hurricane evacuation studies.

1.6.4 Shelter Analysis (Chapter Five)

The Shelter Analysis presents a current inventory (October 1996) of American Red Cross Mass Care Facilities and locally identified public shelters. The inventory was assembled with the assistance of the American Red Cross and local emergency management officials. Flood Insurance Rate Maps were used to identify public shelters susceptible to freshwater flooding. The shelter analysis also lists the estimated shelter utilization and total reported shelter capacity for each community. The estimated shelter utilization was calculated by applying the shelter utilization rates listed in **Table 4.2** to the evacuating population estimates listed in **Tables 3.1** and **3.2**.

1.6.5 Transportation Analysis (Chapter Six)

The results of the previous analyses were used in the Transportation Analysis to estimate the total time it would take to clear traffic from roadways after public dissemination of a regional level evacuation recommendation. A computer transportation model was used to represent the major routes and many local routes in the study area. The model was used to forecast how competition for roadway space by evacuating traffic and traffic from other trip purposes may impact each other and possibly delay an overall evacuation. Other trip purposes include, for example, people leaving work early or making last minute shopping trips. Roadway clearance times were estimated for evacuations considering weak and severe hurricane events, a range of initial traffic conditions, and a range of evacuee response times. Evacuee response time is the amount of time it takes the public to mobilize and leave their homes.

1.6.6 Evacuation Times (Chapter Seven)

Estimated roadway clearances times are calculated in the transportation analysis for 18 possible evacuation scenarios based on the sensitivity of clearance times to varying hurricane severity, initial traffic conditions, and evacuee response time. A range of evacuation scenarios was considered to qualify the most likely evacuation situations which officials might have to contend with when deciding if, and when, to issue an evacuation recommendation or order. In chapter 7, the rationale for using a single clearance time for most evacuation situations is presented. A single clearance time is recommended to assist in implementing a coordinated state and local evacuation. Furthermore, this chapter explains the importance of another component of evacuation time, termed dissemination time, which must be combined with clearance time to accurately estimate total evacuation time.

1.6.7 Decision Analysis (Chapter Eight)

The Decision Arc Method is a hurricane evacuation decision making tool that uses evacuation times, in conjunction with National Hurricane Center advisories, to calculate when evacuations should begin in order for them to be completed before the onset of initial hurricane hazards. The Decision Analysis presents a step-by-step procedure for using the Decision Arc Method.

1.7 STUDY COORDINATION

A comprehensive coordination program was established for the Southern Massachusetts Hurricane Evacuation Study that included the Massachusetts Emergency Management Agency, FEMA, Corps of Engineers, National Weather Service, American Red Cross, local chief elected officials and local emergency management directors. Several coordination meetings with study area communities were sponsored by the Massachusetts Emergency Management Agency, FEMA, and the Corps of Engineers to assure proper and thorough data gathering and coordination of the study, and to provide maximum flexibility in the study. Coordination meetings provided opportunities for product end-users to review and comment on preliminary results as analyses were completed. Draft inundation maps, draft evacuation maps, and preliminary results distributed for review by State and local emergency management officials served as interim products until final products were completed. The information contained in this report, its appendices, and associated atlases replaces all draft information previously released.

Chapter Two

HAZARDS ANALYSIS

2.1 PURPOSE

The purpose of the Hazards Analysis is to quantify the surge heights for various intensities and tracks of hurricanes considered to have a reasonable meteorological probability of occurrence within a particular coastal basin. Potential freshwater flooding from rainfall accompanying hurricanes is also discussed, however, due to the wide variation in amounts and time of occurrence from one storm event to another, rainfall is addressed only in general terms. Officials are encouraged to use FEMA's Flood Insurance Rate Maps when planning evacuations in non-tidal areas.

The primary objective of the Hazards Analysis is to determine the probable worst-case flooding effects from various intensity hurricanes that could strike the region. It is important to note that maximum storm surge heights are not derived from a single hurricane event. Instead, maximum storm surge, or worst-case storm surge, is defined as the highest rise in still water elevation which can potentially occur for a particular location when all hurricanes with a reasonable likelihood of occurrence are considered. The potential surge tide is maximized by having the surge arrival coincident with the astronomical high tide. The worst-case surge height for each meteorological scenario was determined by varying three critical parameters: landfall point, track direction, and forward speed. Emphasis of worst-case surge heights in this analysis is considered appropriate for the purpose of hurricane evacuation planning (i.e., the protection of people).

The majority of lives lost and property damage from hurricanes has been due to surge flooding. The principal function of the Hazards Analysis is, therefore, to develop accurate estimates of potential surge heights. This focus on hurricane surge does not reflect a discounting of the dangers of hurricane winds. Wind damages to structures are extremely difficult to predict considering the uncertainties involved in forecasting the track of a hurricane and the resultant wind forces applied to structures at ground level. The National Weather Service, through its National Hurricane Center, issues warnings and advisories which give detailed forecasts on expected sustained wind speeds and peak wind gusts. These forecasts help to prepare officials and the public for wind hazards, but there is little certainty what affects these winds may have on various structures in the region.

The Decision Arc Method presented in Chapter Eight, discusses how officials may use the results of this study together with National Hurricane Center advisories for determining when an evacuation must be initiated in order for it to be completed before gale force winds arrive.

2.2 FORECASTING INACCURACIES

The worst-case approach was used in presenting possible hurricane surge effects because of the inherent inaccuracies in forecasting the precise track and other meteorological parameters of hurricanes. An analysis conducted by the National Hurricane Center of hurricane forecasts suggests that a substantial margin of error exists with each forecast issued. From 1982 to 1991, the average error in the official 24-hour hurricane track forecast was 120 statute miles. The average error in the 12-hour official forecast was 62 statute miles.

To illustrate how these errors complicate evacuation decision-making, consider a hurricane that is forecasted to make landfall at the Rhode Island/Massachusetts border in 12 hours time. If this storm were to actually landfall anywhere between the vicinity of East Lyme, Connecticut and Chatham, Massachusetts, the resulting error in forecasted landfall location would be no worse than average. Stated another way, suppose that a hurricane that is forecasted to make landfall along the coast of Rhode Island in 12 hours actually hits Cape Cod directly. The track error associated with this storm would be within the National Hurricane Center's typical error range. It follows from these examples that Massachusetts is potentially vulnerable to every hurricane forecasted to reach the New England region.

Similar error analyses conducted for forecasted hurricane wind speed showed that the average error in the official 24-hour rotational wind speed forecast is 15 mph and the average error in the 12-hour official forecast is 10 mph. Decision-makers should note that an increase of 10 to 15 mph in rotational wind speed can raise the intensity of the approaching hurricane one category on the Saffir/Simpson Hurricane Intensity Scale. Because wind speed is the primary influence on storm surge generation, an increase in rotational wind speed will also contribute to higher surge heights.

Most hurricanes which travel to New England undergo significant acceleration in forward speed with further northward movement over the cooler waters of the mid-Atlantic. As with errors in landfall forecasts, errors in the forecasted forward speeds of hurricanes can also complicate evacuation decision-making. If there is uncertainty in the forecasted forward motion of a hurricane, then there will inherently be some uncertainty in the timing at which the storm is expected to reach a certain location. If a storm accelerates unexpectedly, or if it accelerates at a greater rate than anticipated by weather officials, then the hurricane will arrive earlier than indicated by forecasts. Should a storm unexpectedly accelerate, officials will have to evacuate residents more quickly or risk not completing the evacuations in time.

In southern Massachusetts, an increase in a hurricane's forward speed may have a greater effect on the resulting storm surge than an increase in the storm's intensity. Faster moving, weaker intensity hurricanes may cause more flooding in some areas than slower moving, more intense hurricanes. Specific hurricane modeling examples illustrating this phenomenon are discussed in Section 2.5.5.

2.3 STORM SURGE

2.3.1 General

Abnormal high water levels along ocean coasts and interior shorelines are commonly caused by storm events. These higher than expected water levels are mostly due to storm surges produced from the combination of winds and low barometric pressure. Along the north Atlantic seaboard, extratropical storms such as "northeasters" have produced some of the highest storm surges and resultant damages on record. However, hurricanes have the potential to produce much higher storm surges because of the vast amount of energy that can be released over a relatively short duration. Storm surges can affect a shoreline over distances of more than 100 miles. However, there may be significant spatial variations in the magnitude of the surge due to local bathymetric and topographic features.

Storm surge is defined as the difference between the observed water level and the normal astronomic tide. Astronomic tides represent the periodic rise and fall of the water surface resulting from the gravitational attractions of the moon, sun, and Earth. Positive surges occur when the observed water level exceeds the height of the predicted astronomic tide. Negative storm surges (lower than expected water levels) are produced primarily in lakes, semi-enclosed basins, and bays. These negative surges are considered more of a nuisance, such as a temporary hindrance to navigation, than a true natural hazard. It is the positive surge which has the greatest potential for property damage and loss of life.

2.3.2 Generation of Storm Surge

There are a number of factors which contribute to the generation of storm surges but the fundamental forcing mechanism is wind and the resultant frictional stress it imposes on the water surface. Winds blowing over a water surface generate horizontal surface currents flowing in the general direction of the wind. These surface currents in turn create subsurface currents which, depending on the intensity and forward speed of the hurricane, may extend from one to several hundred feet below the surface. If these currents are in the onshore direction, water begins to pile up as it is impeded by the shoaling continental shelf, causing the water surface to rise. The water level will increase shoreward until it reaches a maximum at the shoreline or at some distance inland. The most conducive bathymetry for the formation of large storm surges is a wide, gently sloping continental shelf.

The reduction of atmospheric pressure within the storm system results in another surge-producing phenomenon known as the "inverted barometer" effect. Within the region of low pressure the water level will rise at the approximate rate of 13.2 inches per inch of mercury drop. This can account for a rise of one to two feet near the center of the hurricane. This effect is considered to be a more important factor in the open ocean, where the surge produced by wind is negligible.

2.3.3 Factors Influencing Storm Surge

The magnitude of storm surge within a coastal basin is governed by both the meteorological parameters of the hurricane and the physical characteristics of the basin. The meteorological aspects include the hurricane's size, measured by the radius of maximum winds; its intensity, measured by sea level pressure and maximum surface wind speeds at the storm center; its path, or forward track of the storm; and the storm's forward speed. The radius of maximum winds is measured from the center of the hurricane to the location of the highest wind speeds within the storm. This radius may vary from as little as

4 miles to as much as 50 miles. The counterclockwise rotation of the hurricane's wind field in combination with the forward motion of the hurricane typically causes the highest surge levels to occur to the right of the hurricane's forward track.

2.4 STORM SURGE (SLOSH) MODEL

2.4.1 Introduction

Computer models representing the varying bathymetry and other factors affecting storm surge have been developed for specific coastal basins to mathematically simulate surges from hurricanes. Because there is not sufficient historic information from which valid assessments can be made about a basin's surge potential, estimates used in this study are based on simulations using a computer model rather than observed information from actual hurricanes. The Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model is the latest and most sophisticated mathematical model developed by the National Weather Service to calculate potential surge heights from hurricanes. It calculates storm surge heights for the open ocean and coastal regions affected by a given hurricane. The model also calculates surge heights for bays, estuaries, coastal rivers, and adjacent upland areas susceptible to inundation from the storm surge. Significant manmade or natural barriers (i.e., hurricane barriers, dunes, islands, etc.) can be represented by the model such that their effects are simulated in the calculation of surge heights.

The SLOSH model was first developed by the National Weather Service and used by the National Hurricane Center for real-time forecasting of surges from hurricanes within selected Gulf of Mexico and Atlantic coastal basins. The National Hurricane Center's success in surge forecasting has lead to utilization of the Model for hurricane preparedness planning. Consequently, the National Weather Service's SLOSH model results have become the foundation for Hurricane Evacuation Studies sponsored by FEMA and the Corps of Engineers under their national program.

The SLOSH model was applied to this study to simulate the effects of hypothetical hurricanes which could realistically impact Massachusetts, and to simulate actual hurricanes which have affected the Commonwealth in the past. SLOSH model coverage to the southern Massachusetts study area was provided through the development of the Narragansett Bay/Buzzards Bay SLOSH Basin shown in **Figure 2.1a** and the Boston Bay SLOSH Basin shown in **Figure 2.1b**. More detailed information about the two SLOSH

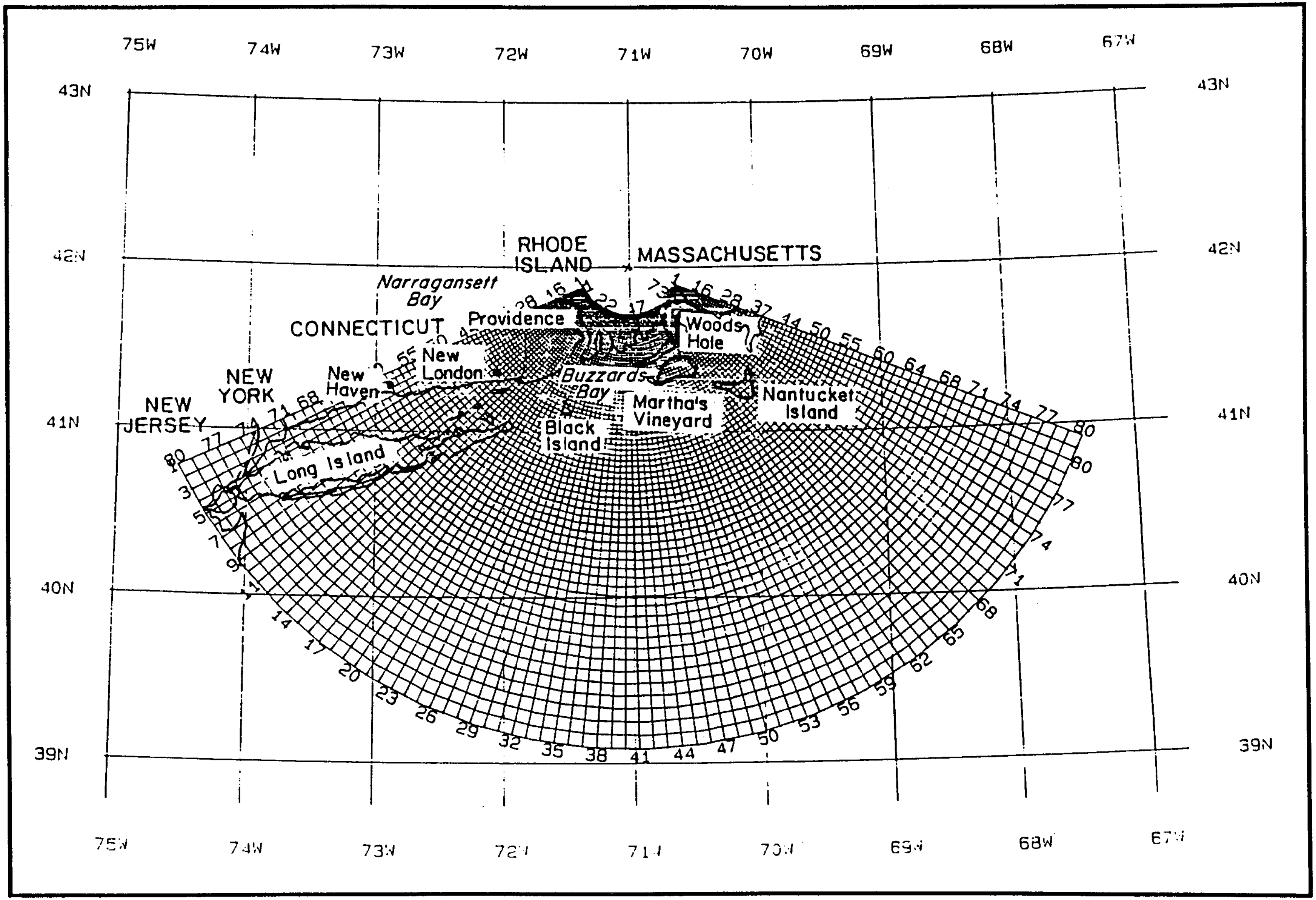

Figure 2.1a Narragansett Bay/Buzzards Bay SLOSH Basin.

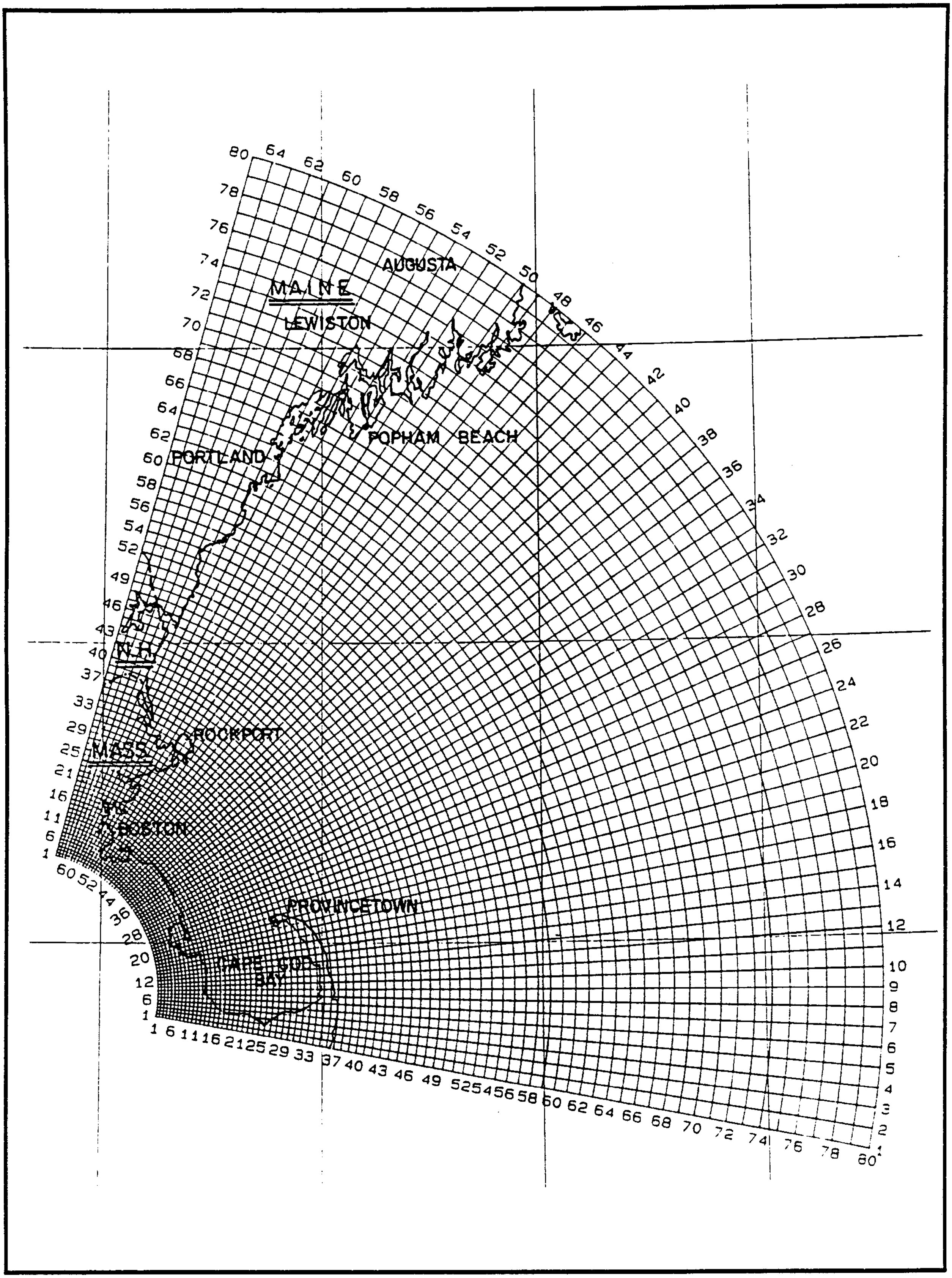

Figure 2.1b Boston Bay SLOSH Basin.

model basins is presented in Appendix A, A Storm Surge Atlas for Narragansett Bay, Rhode Island and Buzzards Bay, Massachusetts Area, and Appendix B, A Storm Surge Atlas for the Boston Bay, Massachusetts Area. The information in Appendices A and B was prepared by the National Hurricane Center specifically in support of this study.

The initial step in applying the SLOSH model to a particular region is to incorporate the three-dimensional geometry of the features which will influence surge. This includes specifying the water depths over the continental shelf, nearshore zone, estuaries, river mouths, and adjacent bodies of water; as well as the land elevations of the intertidal and upland areas.

In the SLOSH model, a storm event is represented by the following types of data:

a. Latitude and longitude of storm positions at six-hour intervals for a 72 hour period.

b. The atmospheric pressure at sea level in the eye of the hurricane.

c. The storm size measured as the radius of maximum wind.

The storm's wind speeds are not directly input by the modeler; instead, the SLOSH model calculates a radial surface wind profile from the meteorological parameters outlined above.

2.4.2 Model Structure

Figures 2.1a and **2.1b** show the grid system used by the SLOSH model to represent the basins. The grid allows the modeler to represent the areas of greatest interest, which for this study are the areas nearest to the shore, with the highest resolution. The smaller grid size along the shore allows more detailed representation of physical features, such as inlets, rivers, islands, dunes, etc., which can have important effects on the development of the storm surge. In general, grid sizes range from one square mile at the grid focus and increase to 42 square miles in fringe areas. The reduced number of cells in the offshore area reduces the computing time and expense of each model run required. Larger grid cell size in the offshore region permits the inclusion of a large geographic area in the model so that effects along the basin's boundaries are diminished.

2.4.3 Model Verification

After a SLOSH model has been constructed for a coastal basin, the accuracy of the model is verified by inputting meteorological data from prior storms. The data contains observed storm meteorological parameters from hindcasts of actual hurricanes and the initial observed sea surface height 48 hours before the storm's landfall. The computed surge heights are compared with those measured from historical storms and, if necessary, adjustments are made to universal parameters such as drag and bottom stress coefficients, or actual basin data.

These adjustments are not made to force agreements between computed and observed surge heights, but to calibrate the model to more accurately represent the basin characteristics. In instances where the model gives realistic results in one area of a basin but not in another, closer examination of the basin often reveals inaccuracies in the representation of barrier heights or missing values in bathymetric or topographic charts. Before commencing hurricane simulations, the modeler conducts field investigations and verifies that topographic information input into the model agrees with actual coastline topography.

Prior to widespread application of the SLOSH model for hurricane evacuation planning, the model underwent a series of verification tests performed by the National Weather Service. Nine hurricanes with well documented meteorology and storm surge effects were each modeled for at least one of nine discrete basins. The SLOSH model's performance in these verifications justified its present use as a hurricane planning tool. Prior to 1985, only sparse records of complete time history data of hurricane meteorology and storm surge observations existed for the Narragansett/Buzzards Bay SLOSH Basin and the Boston Bay SLOSH Basin. The occurrence of Hurricane Gloria in September 1985 offered an opportunity to verify SLOSH model predictions within the basin at several Rhode Island and Massachusetts locations.

The accuracy of the SLOSH model has been evaluated using approximately 540 surge observations from historical hurricanes. To do this, the SLOSH model was programmed to approximate the precise meteorology and tracks of historical events. The computed surge values were then compared to the corresponding observations to determine how well the model performed. The surge observations were obtained from tide gage information, staff records and high water marks. These observations were taken throughout the area affected by the surge, at the periphery and along the inland water bodies. A statistical analysis of the observed data versus the calculated surge values determined an error range of range of +/- 20 percent for significant surges with a few observations above and below this range.

Actual hurricane events provide the developers of the SLOSH model opportunities to compare observed surge heights to the theoretical surge heights. The National Hurricane Center evaluated the SLOSH model's performance for Hurricane Bob, which struck New England in August 1991. **Figure 2.2** graphically compares SLOSH model surge height estimates to the observed surge levels recorded at tide gages.

In **Figure 2.2**, Hurricane Bob's track is represented by the solid straight line extending in a north-northeast direction over Rhode Island and Massachusetts. The smooth curved lines shown staggered over the ocean waters delineate one foot contours of the SLOSH model's surge estimates. SLOSH surge height estimates are shown for several sites along the coast to include those sites where tide gages are located. Circled values denote the maximum observed surge height recorded at tide gages. Values which are not circled are the SLOSH model's surge height estimates. All surge heights are given in feet referenced to the National Geodetic Vertical Datum (NGVD).

As expected, and illustrated by the surge contours in **Figure 2.2**, SLOSH surge estimates rapidly increased to the "right of the eye" as ocean water funneled northward into Buzzard's Bay. In Bourne, Massachusetts, near the south entrance of the Cape Cod Canal, the surge predicted by the SLOSH model exactly matched the 9.1 foot surge that was observed. Likewise, the SLOSH model performed equally well at the Fox Point Hurricane Barrier in Providence, Rhode Island. At this location, the SLOSH model's maximum surge estimate and the observed maximum surge were 6.6 feet (NGVD).

Figure 2.3 shows the observed storm surge at tide gages located in Newport, Rhode Island and Woods Hole, Massachusetts to SLOSH computed storm surge at these same locations. The forecasted surge, when compared to the observed surge, overestimated heights at times before maximum surge occurs. At times after maximum surge heights occur, the SLOSH model underestimated observed heights. The forecasted and observed times at which maximum surge occurred were the same at Newport. At

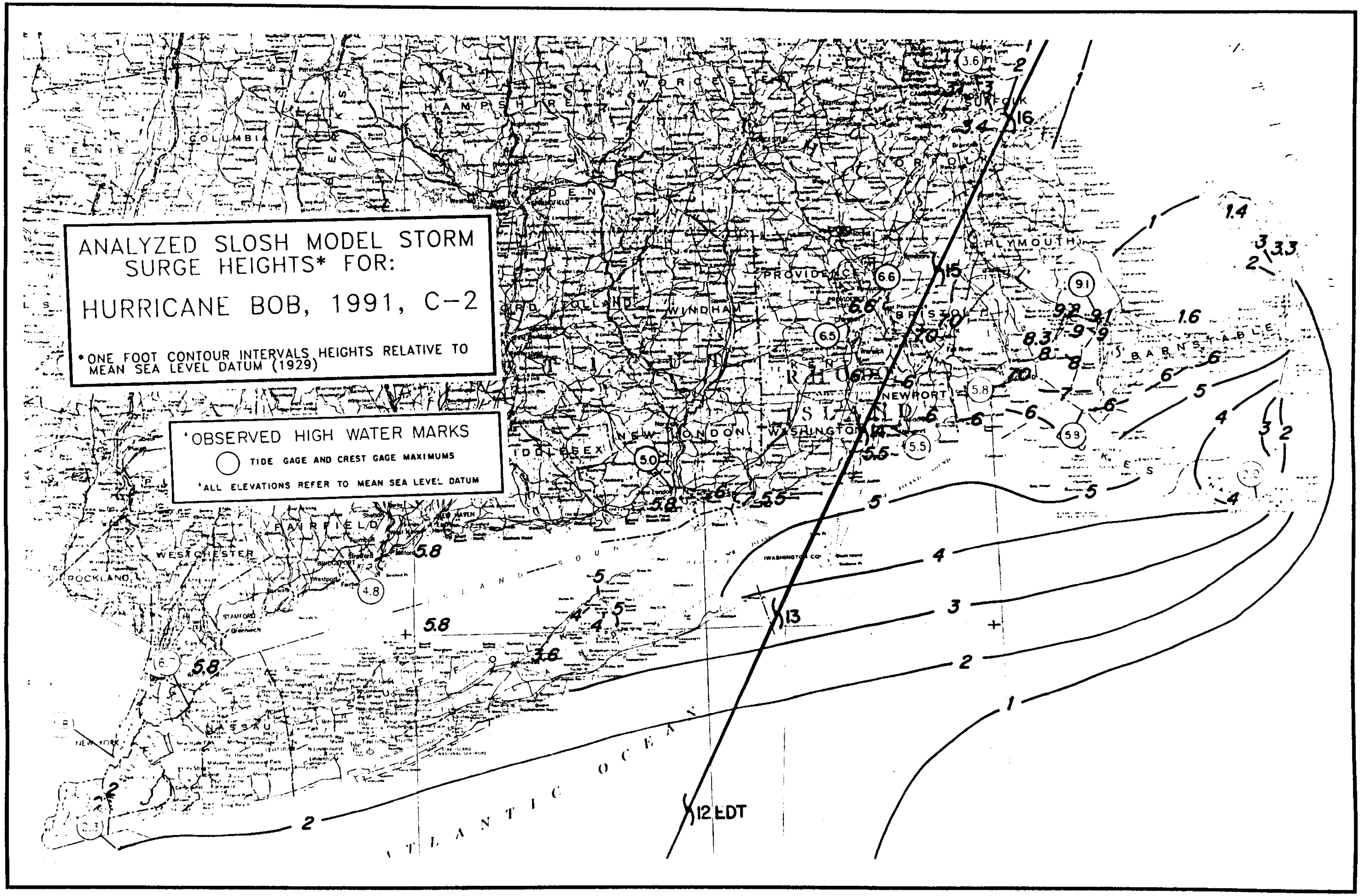

Figure 2.2 SLOSH Model Surge Heights vs. Observed Surge Heights, Hurricane Bob, 1991.

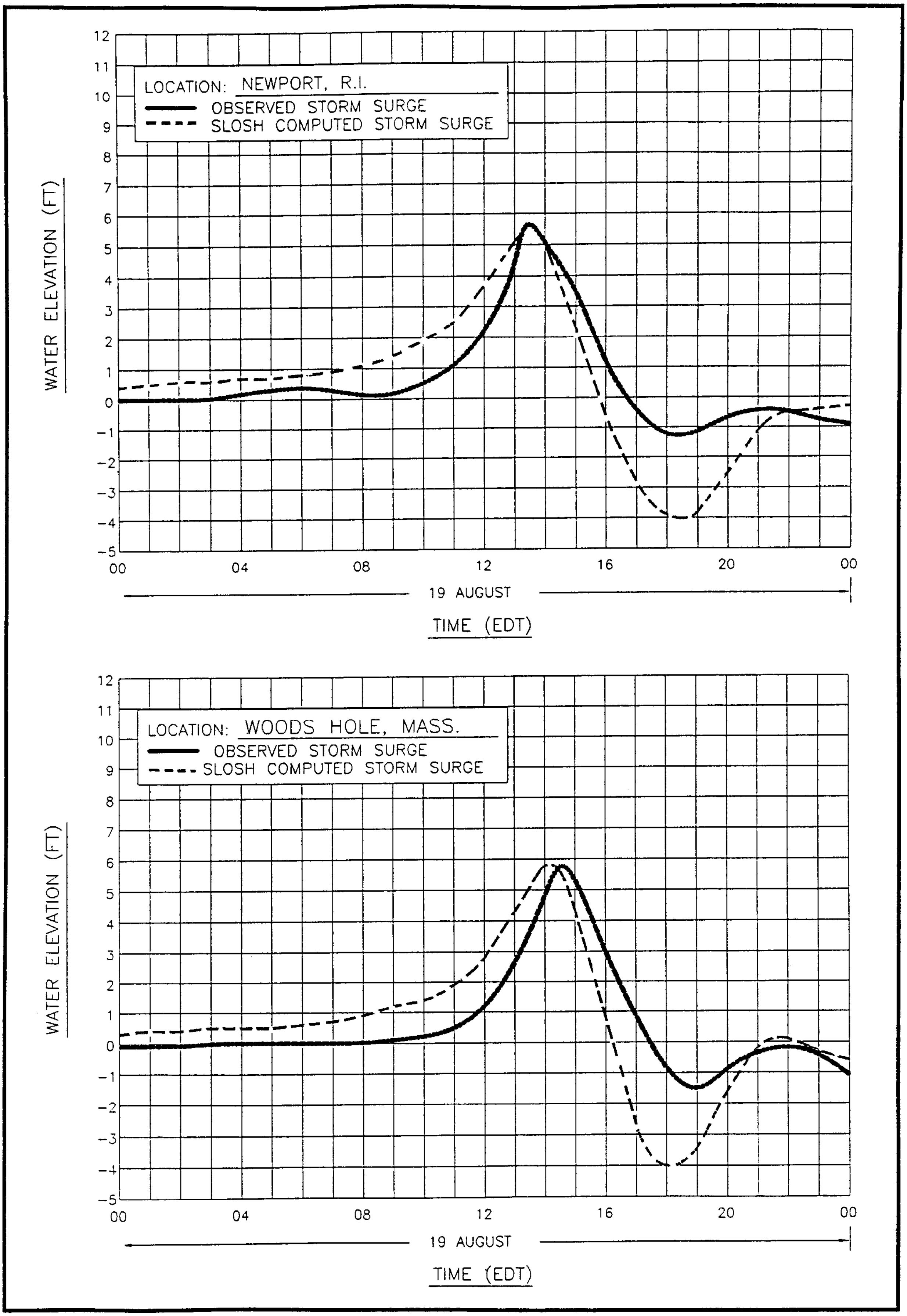

Figure 2.3 SLOSH Model Surge vs. Observed Surge at Newport, RI and Woods Hole, MA, Hurricane Bob, 1991.

Woods Hole, the forecasted maximum surge height matched the observed height, but the forecasted maximum surge was predicted to occur approximately 30 minutes sooner than it actually did.

Overall the SLOSH model preformed well. At all tide gage locations shown in **Figure 2.2**, maximum surge estimates were within a few tenths of a foot of observed levels, and the times at which maximum heights were predicted to occur were within an hour of their actual occurrence.

2.4.4 Model Output

The standard output from a SLOSH model run consist of both tabulated and graphical information. The tabulated output consists of the following:

a. A printout of the meteorological values used to represent the hurricane being modeled. Printed meteorological values include: latitude and longitude of the storm's center, central pressure differential, and storm size (radius of maximum winds) at six hour intervals during its 72 hour track.

b. Assumed starting water surface elevation of the basin.

c. Interpolated meteorological values calculated by the model every hour during its 72 hour track. Interpolated values are determined from meteorological values input by the modeler for each six-hour position. Printed interpolated meteorological values include: latitude and longitude of the storm's center, central pressure differential, radius of maximum winds, track direction, and forward speed.

d. Model computed values of surge height, wind speed, and wind direction at a number of predesignated sites selected by the modeler. These predesignated sites are termed "time-history" locations because the model calculates and prints this data for selected locations every half hour for approximately 48 hours prior to storm arrival and approximately 24 hours after the storm has passed. The model prints only the maximum surges that occurred over the entire 72 hour period at all other grid cells not specified as time history locations.

The graphical output is a grid showing calculated surges for the basin. Each grid cell is plotted at a uniform size, which distorts the coastline configuration and the configurations of other topographic features. In order to plot all grid cells at a uniform size, cells near the origin of the original grid are expanded relative to their original size, and grid cells near the outer portion of the original grid are contracted relative to their original size. The plots provide the maximum water surface elevation attained at each grid cell over the duration of the hurricane simulated. The plot does not represent a "snapshot" of the storm surge at an instant of time. Instead, it represents the highest water level at each grid point during a hurricane irrespective of the actual time of occurrence during that storm. This plot of maximum surge heights is referred to as the "envelope" of maximum surge for a particular storm. Refer to Appendices A and B for a for the plotted envelopes of maximum surge for the storm scenarios modeled.

A certain degree of caution should be considered when viewing the results of the SLOSH model runs. All hypothetical hurricanes had a radius of maximum winds 30 miles from the eye's center. Typical radii of maximum winds of actual storms do not remain fixed and can range from about 4 miles to approximately 50 miles. Even slight expansions or contractions of a storm's radius of maximum winds can mean large differences in the storm surge generated at a particular site.

2.5 COASTAL MASSACHUSETTS SLOSH MODELING PROCESS

2.5.1 Introduction

The geographic area covered by the SLOSH model of the Narragansett/Buzzards Bays Basin includes: all coastal areas in Rhode Island including the upper reaches of Narragansett Bay; portions of southern Massachusetts from the Rhode Island border through Buzzards Bay, the Elizabeth Islands, Martha's Vineyard, Nantucket, to approximately the town of Chatham on Cape Cod. The geographic area covered by the SLOSH model of the Boston Bay Basin includes: the Massachusetts coastline from approximately the town of Chatham through the outer Cape, Cape Cod Bay, the south shore, Boston Harbor and the harbor islands, the north shore; the coast of New Hampshire, and the coast of Maine from the New Hampshire border to approximately the towns of Camden and Rockport.

2.5.2 Simulated Hurricanes

A total of 536 and 516 hypothetical hurricanes were modeled in the Narragansett Bay/Buzzards Bay and Boston Bay SLOSH models, respectively. These storms were derived by specifying four influential parameters for each event: the track, direction of travel, forward speed; and hurricane intensity. The National Hurricane Center selected storm parameters based on the region's historic hurricane activity and their assessment of probable storms which could be sustained by the region's meteorological climate. In total, combinations of six storm directions (WNW, NW NNW, N, NNE, NE), four intensities (Categories 1 through 4 on the Saffir/Simpson scale), three forward speeds (20, 40, and 60 mph), and storm tracks at 15-mile intervals were considered. The modeled hurricane tracks are shown in Appendices A and B.

The National Hurricane Center eliminated from the analysis any hypothetical hurricanes which could not realistically be expected to occur in the region. For example, hurricanes that follow a severe westerly or easterly track were modeled with forward speeds of 20 and 40 mph only because they believed that faster storms could not move in these directions. The reasoning for this is that a strong blocking front in the north must be present for hurricanes to track in these directions. The presence of such a blocking front precludes the meteorological conditions necessary for a hurricane to travel in these directions at forward speeds greater than 40 mph. Therefore, the elimination of these storms from the analysis is justified.

The National Hurricane Center also eliminated category 5 hurricanes from the analysis because New England's meteorological climate can not sustain hurricanes of this intensity. Hurricanes extract energy from the warm, moist air over the ocean. The cooler ocean waters of the mid-Atlantic and off-shore of New England tend to reduce the intensity of passing hurricanes. This weakening process, which almost always occurs, is the reason that category 5 hurricanes have an extremely low probability of occurring in New England. However, emergency management officials should realize that swiftly moving category 3 or 4 hurricanes can generate wind speeds considerably higher than the minimum speed required for category 5 classification on the Saffir-Simpson scale. Storm surge is mostly caused by wind stresses and therefore hurricanes that travel at greater forward speeds tend to produce higher surges.

2.5.3 Astronomic Tide Height Effects

The ocean's normal tide fluctuates to its maximum and minimum elevations on a cyclical basis approximately every six hours regardless of the arrival of hurricane surge. The tide range (the water surface change from low tide to high tide) along the southern Massachusetts coast varies considerably from one location to another. The outer Cape has the greatest tide ranges within the study area. In each outer Cape community, the tide range on Cape Cod Bay is greater than along the open ocean. Tide ranges within Buzzards Bay are also higher than for most coastal locations along the open ocean, excluding the outer Cape. Tide range fluctuations are particularly important when assessing worst case storm tides. Tide affects can significantly increase or reduce resulting storm tide height depending upon the point in the tidal cycle when peak surge is experienced. For purposes of determining worst case flood elevations, mean high tide elevations were added to all surges computed by the SLOSH model.

Adding mean high tide to surge values to determine potential worst case flood elevations is considered appropriate for this study. Forecast inaccuracies of the National Hurricane Center's advisories make confident determination of when peak surge will arrive and whether it will coincide with high or low tide difficult, if not impossible. Hurricanes that track towards New England have a tendency to accelerate with northward movement. Changes in a hurricane's forward speed make it even more difficult for forecasters to estimate precise landfall times which often lead to greater errors in forecasts. Even slight changes in a storm's forward speed from those forecasted can influence peak surge occurrence such that it arrives six hours earlier or later than originally expected. Applying the assumption that storm surge will be coincident with high tide eliminates the unexpected circumstance of local officials confronting higher storm tides than predicted for a particular event.

2.5.4 Maximum Envelopes of Water (MEOWS)

For a SLOSH model run of a discrete hurricane event, the maximum water level for all grid cells affected by the storm are calculated irrespective of when maximum water levels were attained during the simulation. The imaginary surface defined by the maximum water level in each cell is termed the "envelope" of maximum water surface elevations for the storm. The largest individual value of water surface elevation for a particular storm is termed the peak surge for that event. The location of the peak surge is highly dependent upon where the storm center crosses the coastline (the landfall point). In most instances, the peak surge from a hurricane occurs to the right of the storm path and within a few miles of where the radius of maximum winds is located. This is largely due to the counterclockwise rotation of the wind field surrounding the eye of the hurricane (in the northern hemisphere). If a hurricane makes landfall generally perpendicular to the shoreline, on the right of the landfall point the winds blow toward the shoreline; on the left of the landfall point the winds blow away from the shoreline. It is important to note, however, during an actual hurricane, the parameter with the least forecast accuracy is the point of landfall.

Because of the inability to predict exactly where a hurricane will make landfall, and because it may be necessary to begin evacuations of areas susceptible to hurricane surges before reasonably confident landfall forecasts can be made, it is necessary to predict the highest surge elevations possible for a given hurricane over a range of potential landfall points. In order to achieve this, the SLOSH model is used to develop a map, termed a "MEOW", which is the maximum envelope of water from a number of individual hurricane simulations which differ only in point of landfall. In this manner, the maximum water surface elevations for each grid cell are calculated for a particular hurricane scenario, defined by direction, forward speed and intensity, independent of where the storm actually crosses the coastline. The contour lines show the maximum water surface elevations at all affected points on the grid for all possible landfall points modeled.

The 536 SLOSH model runs for the Narragansett Bay/Buzzards Bay basin and the 516 SLOSH model runs for the Boston Bay basin were grouped such that 52 MEOWs remained for each basin (see Appendices A and B). The MEOWs were then analyzed to determine which changes in storm parameters (i.e., intensity, forward speed, direction) resulted in the greatest differences in the values of peak surges for all locations in the modeled basin. The MEOWs were then grouped according to overall similarities of predicted envelopes of maximum water level over the entire basins.

In general, it was determined that the change in storm intensity and forward speed accounted for the greatest change in potential surge height. Ultimately, it was determined that the MEOWs could effectively be grouped into three distinct classes of hurricane events defined jointly by the storm's intensity and forward speed. The three classes are mapped on the companion Inundation Map Atlas, December, 1995.

2.5.5 Effects of Hurricane Category, Forward Speed, and Direction

The following figures and discussion are included in this report to illustrate how hurricane category, forward speed, and direction affect surge at certain locations. The discussion does not specifically address the impact that point of landfall has on surge heights, since that characteristic is the most difficult to forecast. Rather, several points of landfall, each fifteen miles apart, are modeled for each combination of hurricane category, forward speed and direction. The maximum surge height for that hurricane condition is then used.

This discussion is for illustrative purposes only, and should not replace the surge elevations plotted on the Inundation Map Atlas. Thirty-four locations were selected for this discussion, as listed in **Table 2.1** and shown in **Figure 2.4**. At all locations, a limited set of hurricane conditions were examined. The graphs in **Figures 2.5** through **2.12** show how surge is affected by:

- varying **Hurricane Category** while keeping Hurricane Forward Speed and Hurricane Direction constant;
- varying **Hurricane Forward Speed** while keeping Hurricane Category and Hurricane Direction constant; and
- varying **Hurricane Direction** while keeping Hurricane Category and Hurricane Forward Speed constant.

The top graph in each figure refers to category 1 through 4 hurricanes moving NNE at a forward speed of 20 mph. The middle graph in each figure refers to category 2 hurricanes moving NNE at 20 mph, 40 mph, and 60 mph. The bottom graph in each figure refers to category 2 hurricanes moving at 20 mph in directions ranging from west-northwest to north-northeast. The discussion about each figure only refers to those specific hurricane circumstances at those specific locations. It would be incorrect to make broad generalizations about surge from other hurricane conditions. The Inundation Map Atlas should be used to determine worst case surge potential for particular hurricane conditions. In addition, Plate iii of the Inundation Map Atlas shows the surge elevations for all locations in the study area.

TABLE 2.1
INFLUENCE OF HURRICANE CATEGORY, FORWARD SPEED, AND DIRECTION ON SURGE HEIGHT
LOCATIONS SELECTED FOR DISCUSSION [1]

Location Number	Location	Location Number	Location
1	Horseneck Beach, Westport	18	Hyannis Port, Barnstable
2	South Dartmouth	19	West Dennis
3	New Bedford	20	Chatham (Nantucket Sound)
4	Mattapoisett Harbor	21	Chatham (East Shore)
5	Swifts Beach, Wareham	22	Eastham (East Shore)
6	Monument Beach, Bourne	23	Wellfleet (East Shore)
7	Sippowisett, Falmouth	24	Truro (East Shore)
8	Menemsha, Chilmark	25	Provincetown (Tip)
9	Vineyard Haven, Tisbury	26	Provincetown (Cape Cod Bay)
10	Oak Bluffs	27	Truro (Cape Cod Bay)
11	Edgartown	28	Wellfleet (Cape Cod Bay)
12	Katama, Edgartown	29	Orleans (Cape Cod Bay)
13	Madaket, Nantucket	30	Brewster
14	Brant Point, Nantucket	31	Dennis
15	Siasconset, Nantucket	32	Yarmouth
16	Woods Hole, Falmouth	33	Barnstable
17	Popponesset Beach, Mashpee	34	Sandwich

NOTES:
1. Locations and location numbers are shown on Figure 2.4.

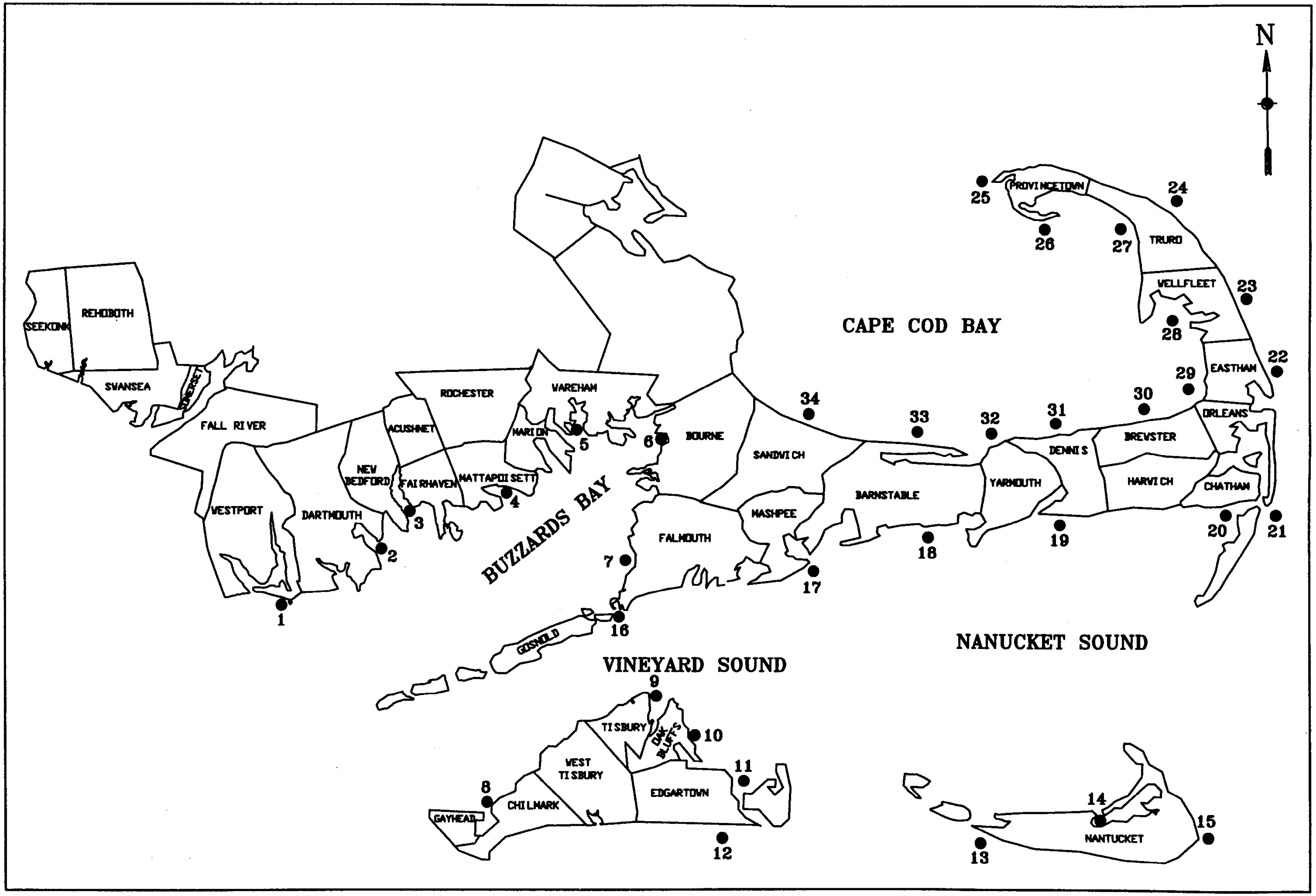

Figure 2.4 Influence of Hurricane Category, Forward Speed, and Direction on Surge Height - Plan of Locations Selected for Discussion.

Bristol County

The graphs in **Figure 2.5** show surge heights at three locations along the south shore of Bristol County: Horseneck Beach in Westport, South Dartmouth, and New Bedford. The graphs show that New Bedford experiences the greatest surge and Horseneck Beach the least surge of the three sites for these conditions. The bottom graph shows that storms moving northeast produce the greatest surge, while storms moving west-northwest produce the least surge at the three locations under these conditions.

Buzzards Bay

The graphs in **Figure 2.6** show surge heights at four locations within Buzzards Bay: Mattapoisett Harbor on the west side of Buzzards Bay, Swifts Beach in Wareham, Monument Beach in Bourne, and Sipowisett in Falmouth. The graphs show that surge heights at the upper end of the Bay are typically higher than at the lower end. Comparing the top graph with the middle graph shows an important point: category 2 hurricanes moving NNE at 40 mph produce higher surge at all four locations than category 3 storms moving NNE at 20 mph. The lower graph shows that for category 2 storms moving at 20 mph, northeast moving storms produce higher surge at these four locations than storms moving in the other directions.

Martha's Vineyard

The graphs in **Figure 2.7** show surge heights at five locations on Martha's Vineyard: Menemsha in Chilmark, Vineyard Haven in Tisbury, Oak Bluffs, Edgartown, and Katama in Edgartown. The top two graphs show that surge heights at the five locations respond similarly to each other to changes in category and forward speed. Comparing the top and middle graphs shows that category 2 hurricanes moving NNE at 40 mph produce higher surge at all five locations than category 3 storms moving NNE at 20 mph. At Menemsha and Vineyard Haven, category 2 hurricanes moving NNE at 40 mph produce higher surge than even category 4 storms moving NNE at 20 mph, which shows the profound influence that hurricane forward speed has on surge height.

At all locations except Edgartown, the lower graph shows that for category 2 storms moving at 20 mph, northeast moving storms produce higher surge than storms moving in the other directions. At Edgartown, surge did not vary much by hurricane direction, but the greatest surge for category 2 storms moving at 20 mph occurs when the hurricane is moving west-northwest.

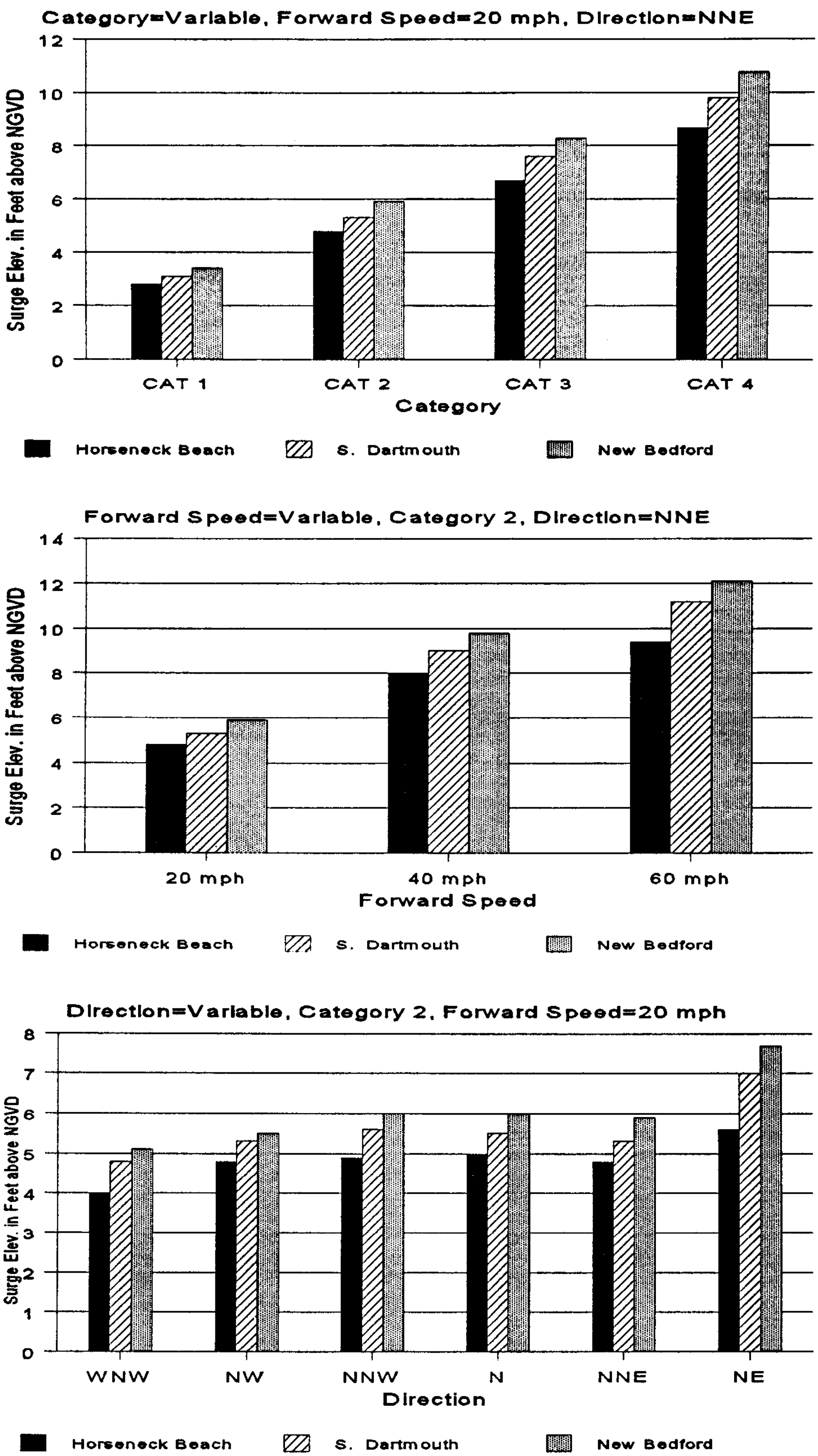

Figure 2.5 Influence of Hurricane Category, Forward Speed and Direction on Surge Heights - Various Locations along the Shore of Bristol County.

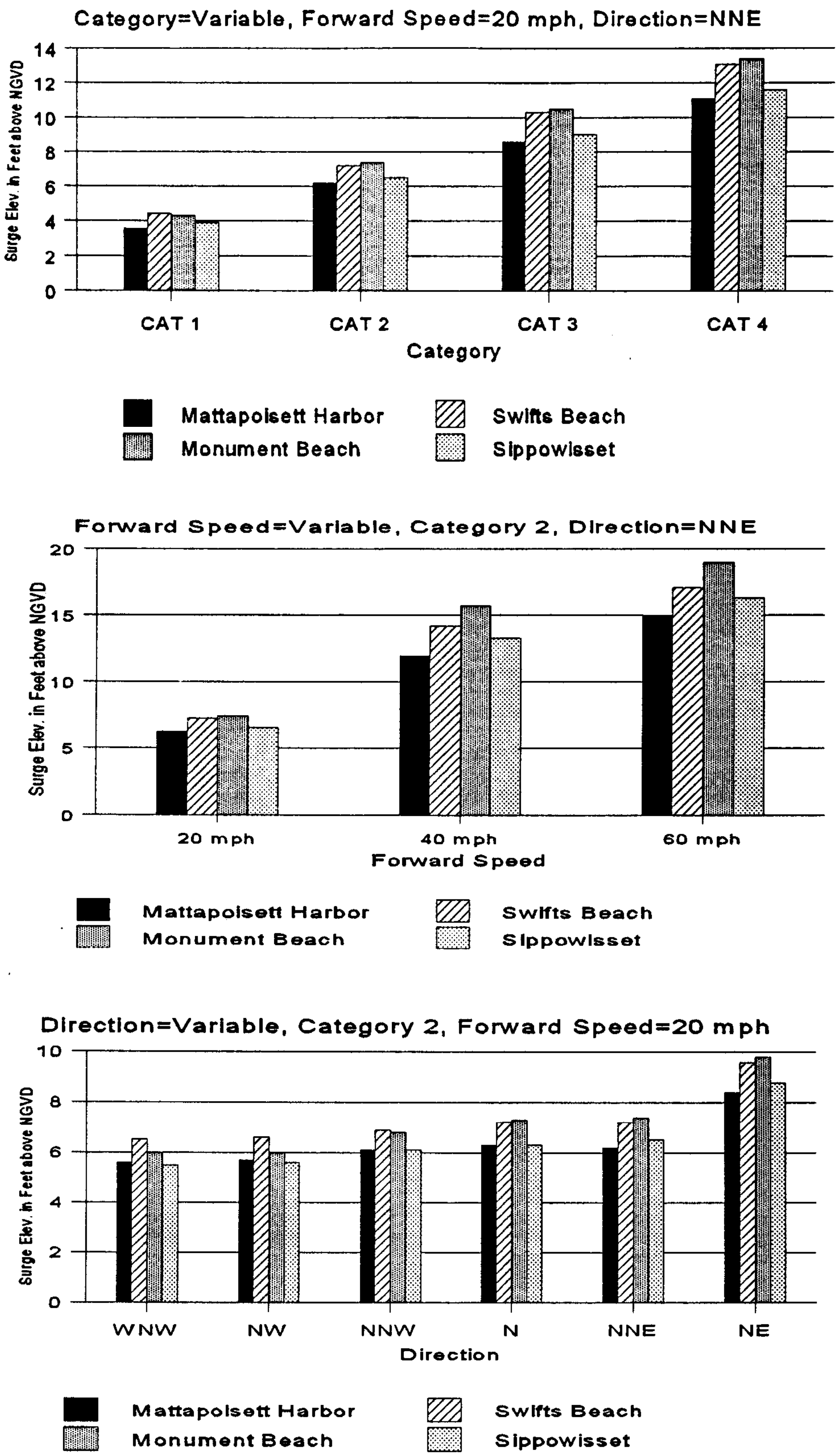

Figure 2.6 Influence of Hurricane Category, Forward Speed and Direction on Surge Heights - Various Locations in Buzzards Bay.

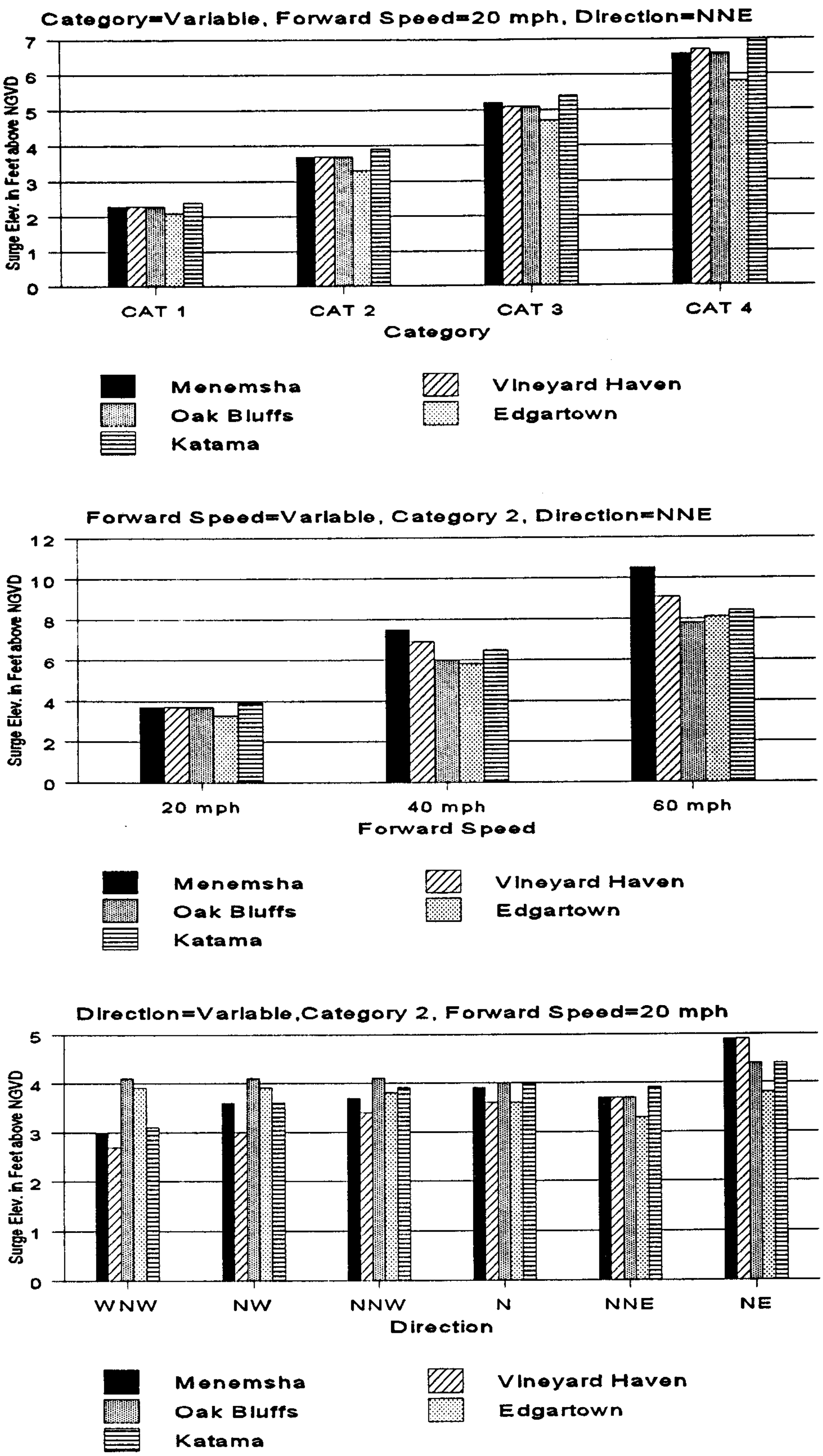

Figure 2.7 Influence of Hurricane Category, Forward Speed and Direction on Surge Heights - Various Locations on Martha's Vineyard.

Nantucket

The graphs in **Figure 2.8** show surge heights at three locations on Nantucket: Madaket, Brant Point, and Siasconset. The top graph shows that, for hurricanes moving north-northeast at 20 mph, Madaket experiences the highest surge of the three locations for all hurricane categories. The lowest surge of the three locations for the above conditions was at Brant Point.

The middle graph in **Figure 2.8** shows surge heights for category 2 storms moving north-northeast at various forward speeds. For that condition, Madaket once again has the highest surge values of the three locations, but the difference in surge at Brant Point and Siasconset depends on forward speed.

Comparing the top and middle graphs shows that <u>category 2</u> hurricanes moving NNE at <u>40 mph</u> produce higher surge at all three locations than <u>category 3</u> storms moving NNE at <u>20 mph</u>, which is important to note. At Madaket and Siasconset, <u>category 2</u> hurricanes moving NNE at <u>40 mph</u> produce higher surge than even <u>category 4</u> storms moving NNE at <u>20 mph</u>, which is a significant fact.

The lower graph shows surge heights from category 2 storms moving at 20 mph in various directions. At Madaket, the highest surge was produced by northeast moving hurricanes, while at Brant Point and Siasconset, the greatest surge was from west-northwest moving storms.

Lower Cape - South Shore

The graphs in **Figure 2.9** show surge heights at four locations on the south shore of Cape Cod: Woods Hole in Falmouth, Popponesset Beach in Mashpee, Hyannis Port in Barnstable, West Dennis, and Chatham (Nantucket Sound side). The top two graphs show that <u>category 2</u> storms moving north-northeast at <u>40 mph</u> produce a surge greater than or equal to <u>category 3</u> storms moving north-northeast at <u>20 mph</u> at these five locations. It is also interesting to note in the middle graph that the surge increases significantly at Woods Hole as hurricane forward speed increases. For category 2 storms moving at 20 mph, the bottom curve shows that storms moving northeast produce the greatest surge at all five locations. The bottom graph also shows that <u>storm direction</u> has a significant impact on surge heights in these locations.

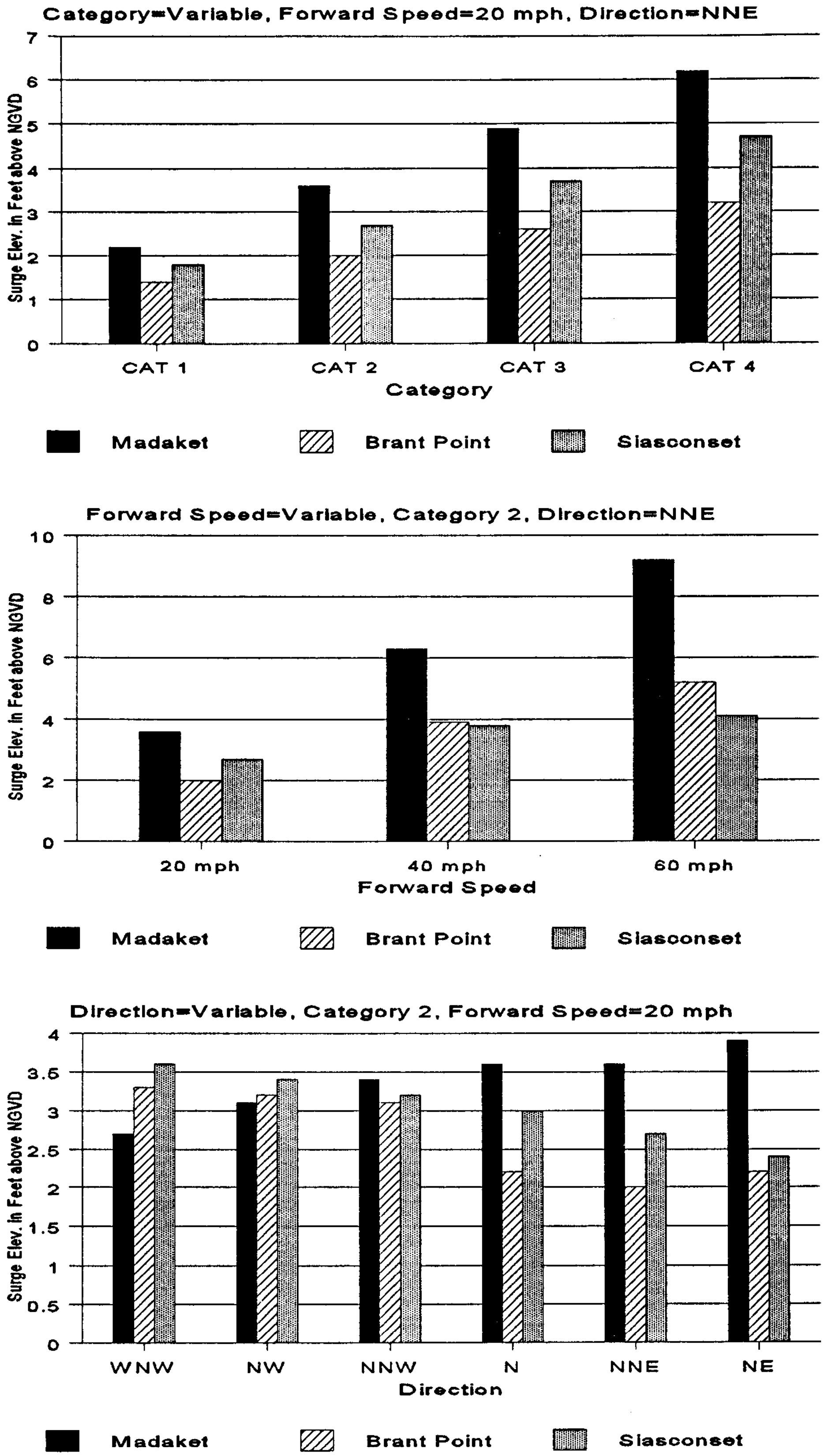

Figure 2.8 Influence of Hurricane Category, Forward Speed, and Direction on Surge Heights - Various Locations on Nantucket.

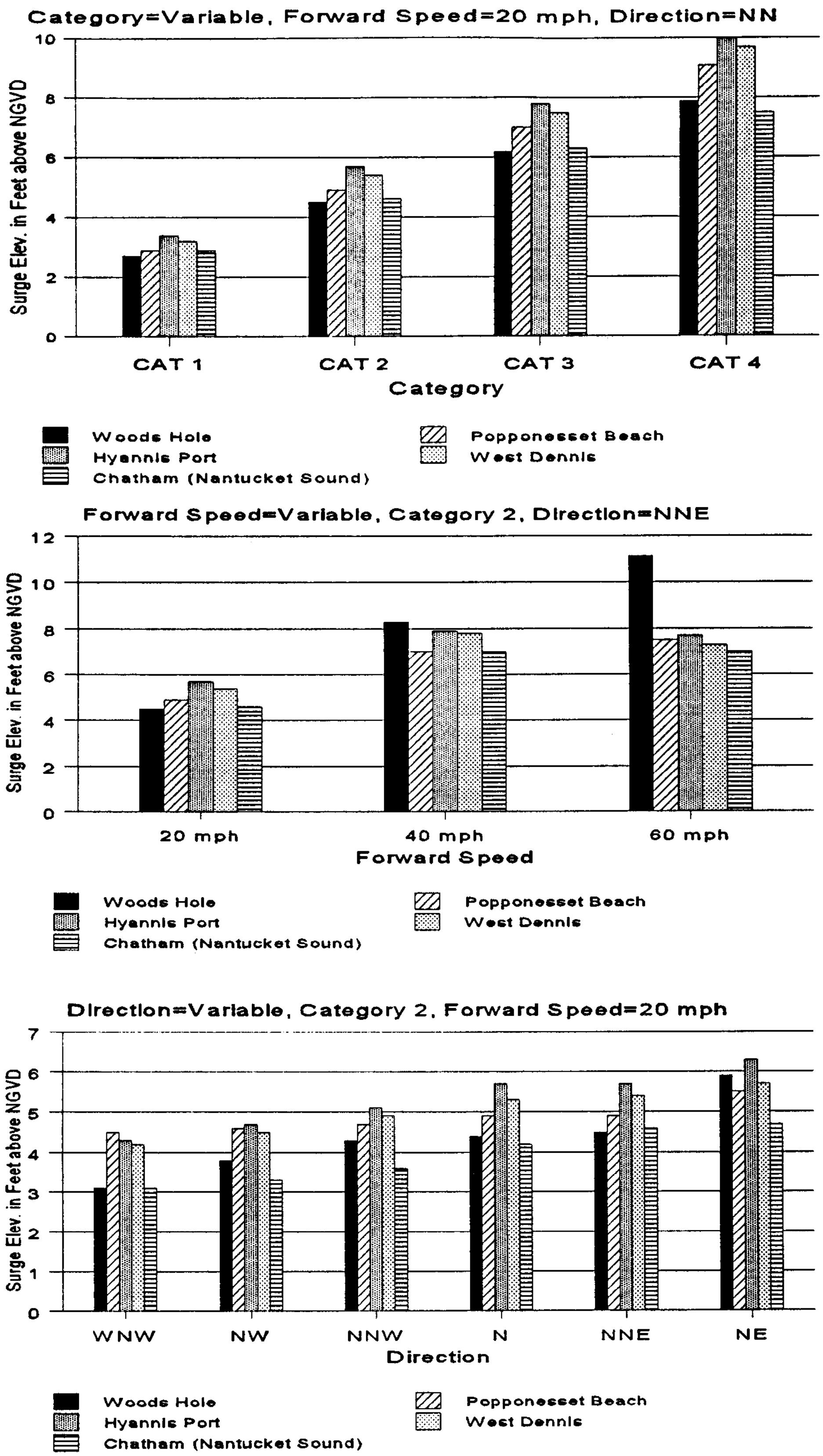

Figure 2.9 Influence of Hurricane Category, Forward Speed and Direction on Surge Heights - Various Locations along the South Shore of Cape Cod.

Upper Cape - East Shore

The graphs in **Figure 2.10** show surge heights at five locations along the east shore of Cape Cod: Chatham, Eastham, Wellfleet, Truro, and Provincetown. The top two graphs show that, unlike the areas shown in **Figures 2.5 to 2.9**, the surge from category 2 hurricanes moving north-northeast at 40 mph is not greater than the surge from category 3 hurricanes moving north-northeast at 20 mph. The bottom graph shows that, for category 2 storms moving at 20 mph, storms moving west-northwest produce the highest surge, and storms moving northeast produce the lowest surge.

Upper Cape - Cape Cod Bay Shore

The graphs in **Figure 2.11** show surge heights at four locations along the Cape Cod Bay shore of the Outer Cape: Provincetown, Truro, Wellfleet, and Orleans. The top two graphs show that the surge from category 2 hurricanes moving north-northeast at 40 mph is not greater than the surge from category 3 hurricanes moving north-northeast at 20 mph, which is what was observed in **Figure 2.10**. The bottom graph shows that hurricane direction does not have much of an affect on surge at Wellfleet and Orleans, and that at Provincetown and Truro, surge is greater for hurricanes with a westerly component to their forward motion.

Lower Cape - Cape Cod Bay Shore

The graphs in **Figure 2.12** show surge heights at five locations along the Cape Cod Bay shore of the Lower Cape: Brewster, Dennis, Yarmouth, Barnstable, and Sandwich. The graphs show that surge heights generally decrease from east to west in this area, with Brewster having the largest surge and Sandwich the smallest. The top two graphs show that the surge from category 2 hurricanes moving north-northeast at 40 mph is not greater than the surge from category 3 hurricanes moving north-northeast at 20 mph, which is what was observed in **Figures 2.10** and **2.11**. The top two graphs also show that hurricane category has a greater impact on surge elevations in this area than hurricane forward speed. The bottom graph shows that hurricane direction has little impact on surge elevations at Brewster, but that for the other four locations, surge is greater for hurricanes with a westerly component to their forward motion.

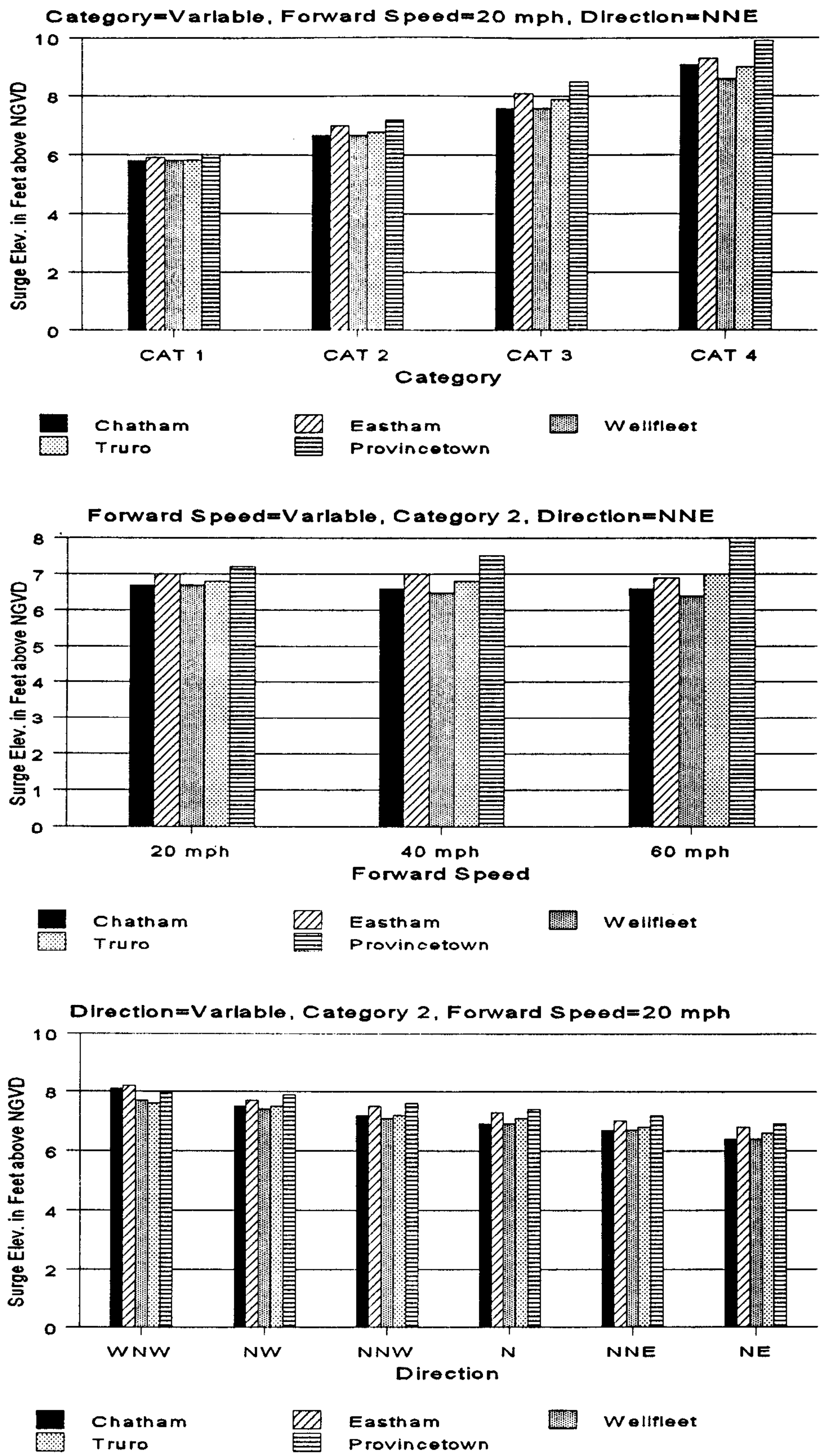

Figure 2.10 Influence of Hurricane Category, Forward Speed and Direction on Surge Heights - Various Locations along the East Shore of Cape Cod.

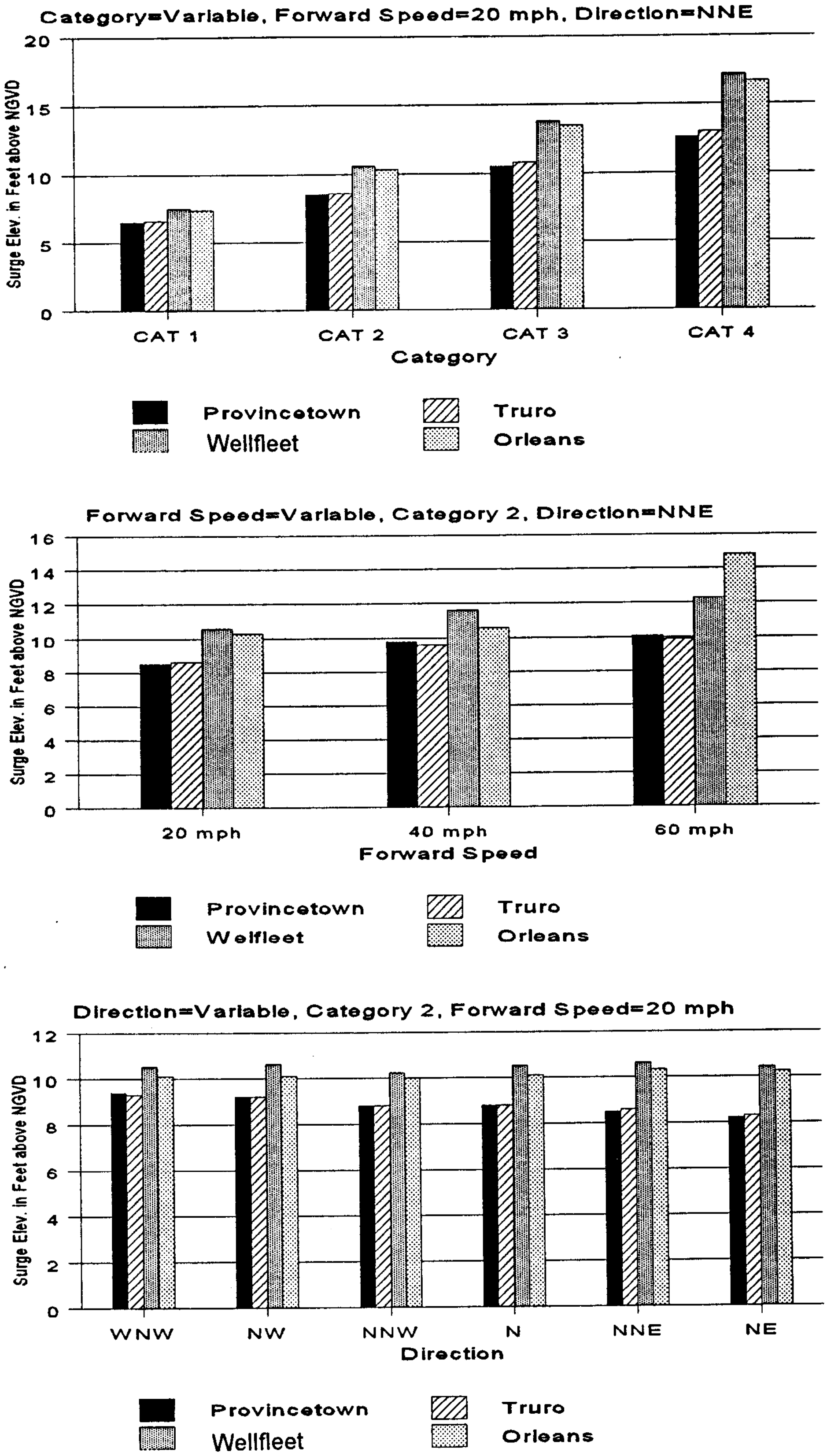

Figure 2.11 Influence of Hurricane Category, Forward Speed and Direction on Surge Heights - Various Locations along the Cape Cod Bay Shore of the Outer Cape.

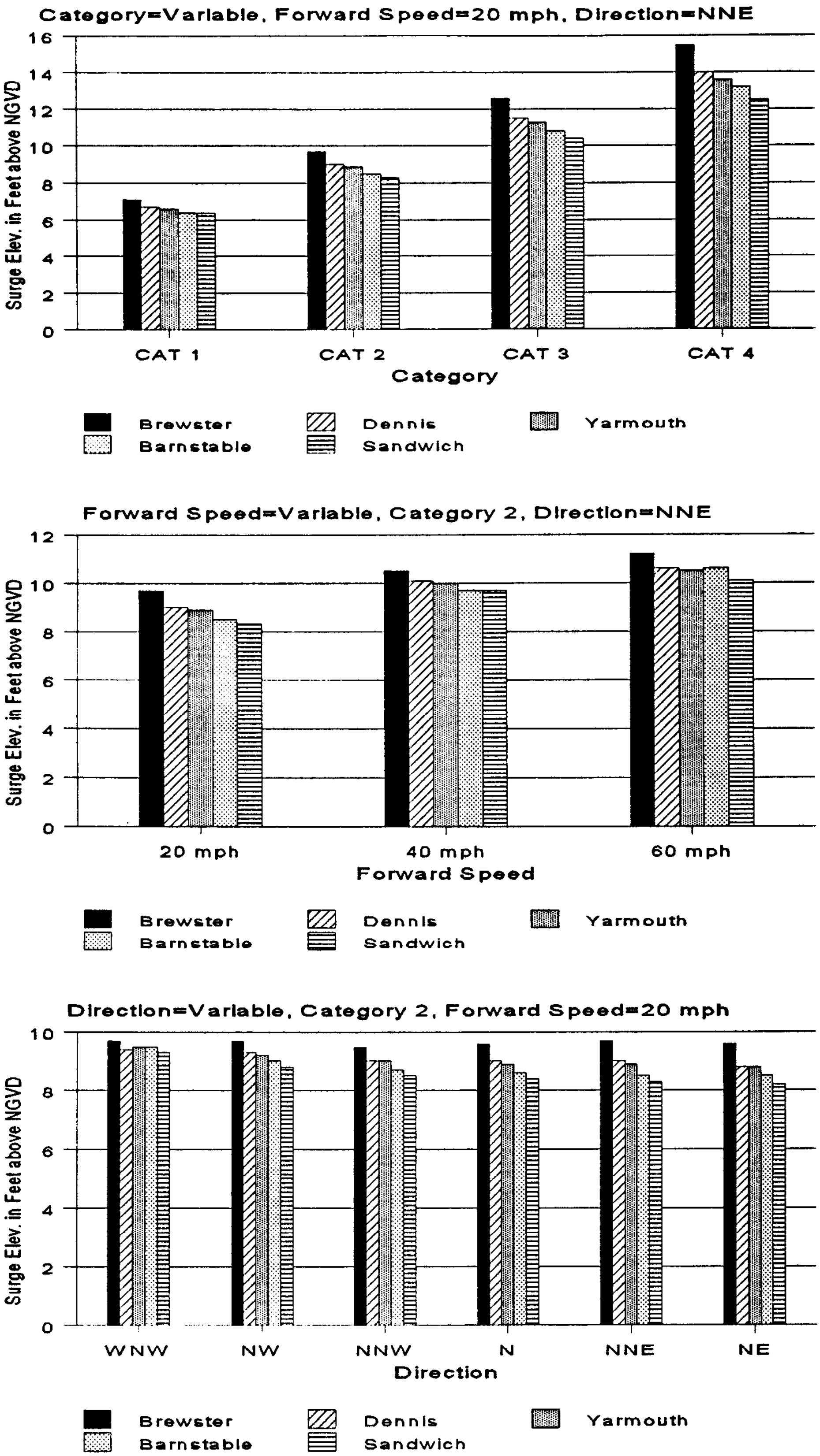

Figure 2.12 Influence of Hurricane Category, Forward Speed and Direction on Surge Heights - Various Locations along the Cape Cod Bay Shore of the Lower Cape.

2.5.6 Wave Effects

Hurricanes have great potential to generate large waves. The size of the waves depends on the force and duration of winds, depth of water, the length of the fetch over which the winds blow, and the affects of natural or man-made obstructions. Waves can runup on shoaling beaches and overtop vertical structures well above stillwater elevations. For evacuation purposes, wave runup was considered to assess whether additional areas, beyond the identified stillwater flooding limits, need to be evacuated.

The SLOSH model does not develop data on the additional water height above maximum stillwater elevations caused by waves and wave runup. For this reason, limited independent wave height and wave runup analyses were performed using worst case stillwater elevations determined by the SLOSH model. It was beyond the objective of this study to determine precise wave heights and wave runup effects for specific locations in the study area. Instead, the objective was to determine a general upper bound on the affects that waves can have on the limits of hurricane surge flooding. It is important to note that wave run-up is dependent upon local shore configuration and that even small differences in coastal topography from location to location can alter wave generation.

Wave height and wave runup analyses were performed for coastal transects taken at representative locations including Mattapoisett, Falmouth, Hyannis and Nantucket, Massachusetts. Transects were selected to represent general shoreline conditions within the study area.

Wave heights and periods were calculated using the wind speed, direction, and duration results from the SLOSH model. Wave runup was calculated using deep water wave heights, stillwater elevation, wave period, and beach slope.

Categories 2 through 4 hurricanes were selected for the analysis. Category 1 storms are the least destructive and for simplicity were omitted from the analysis. Category 5 hurricanes were eliminated from the overall study because of the extremely low probability of a hurricane of this magnitude ever occurring as far north as New England. The hurricane track directions that were analyzed were limited to north-northwest and north-northeast tracks because these tracks were shown to produce the greatest onshore wind speeds and surges at the transects that were analyzed.

The maximum surge associated with each hypothetical hurricane was assumed to occur simultaneously with that storm's maximum wind speed. In addition, the maximum storm surge was assumed to arrive at each location concurrently with the mean high astronomic tide (MHW). Therefore, the maximum anticipated water surface elevation, including wave effects, is the sum of the high astronomic tide elevation, maximum storm surge, and wave runup.

The analysis showed that waves do not significantly extend the land areas flooded by worst case hurricane stillwater, and that wave effects can usually be ignored for purposes relating to the Southern Massachusetts Hurricane Evacuation Study. Since worst case surge inundation areas extend inland beyond open shore areas, waves moving over inundation areas must propagate through areas with roadway embankments, buildings, dunes, vegetation, or other obstructions. The presence of these features drastically reduces wave energy. Frictional losses over inundated areas and the early breaking of waves by obstructions account for most of the dissipated energy. In addition, unimpeded reaches are typically short, which limits the generation of new waves.

For these reasons, it was found that the additional land area of flooding from wave runup, beyond the area flooded by worst case hurricane stillwater, was minimal. This conclusion is valid for all communities within the study area, except locations immediately along the open coastline, or shorelines of very large bays and estuaries where longer fetch lengths and deeper water may exist.

2.5.7 New Bedford Hurricane Barrier

The New Bedford Hurricane Barrier is located in Clark Cove in New Bedford; and in New Bedford Harbor in New Bedford and Fairhaven. The project provides a high degree of tidal-flood protection to an area of about 1,400 acres of heavily developed industrial and commercial properties along the waterfront and the Acushnet River. The project consists of a 4,500 foot long earthfill dike with a 150-foot wide gate opening to accommodate navigation. A 3,600 foot long earthfill dike extension protects the western waterfront. Protection in Clark Cove consists of 5,800 feet of earth dike. The Fairhaven earthfill dike is 3,100 feet long. Other features include two gated conduits and a street gate in the main dike, two street gates and a pumping station in the Clark Cove dike, and a gated conduit in the Fairhaven dike. The Corps of Engineers completed the project in

1966, at which time ownership and responsibility for the majority of the Project's operation and maintenance was transferred to the City of New Bedford. The Corps of Engineers maintains responsibility for operation and maintenance of the Project's navigation gates.

The New Bedford Hurricane Barrier was designed to protect against the "Standard Project Hurricane" to a design stillwater elevation of 16.0 feet (NGVD). The Standard Project Hurricane is defined as "the flood that might be expected from the most severe combination of meteorological and hydrological conditions that are considered reasonably characteristic of the region involved, excluding extraordinarily rare combinations". The meteorological characteristics of the storm used to calculate the Standard Project Hurricane were developed in the late 1950's by the U.S. Weather Bureau (USWB) and the Beach Erosion Board. Storm surge calculations were performed by the Texas A&M Research Foundation. The design storm equivalent to the Standard Project Hurricane was based on the "transposed" Cape Hatteras hurricane of September 1944, with central pressures equal to a category 4 hurricane and a forward speed of approximately 45 mph. The Cape Hatteras hurricane was transposed by giving it a storm track and radius of maximum winds similar to that of the 1938 Hurricane.

The 16.0 foot design stillwater elevation was arrived at by assuming that peak hurricane surge occurs coincident with predicted mean spring high water. Top elevations of exposed portions of the West Dike, Harbor Barrier, and Clark Cove Dike range as high as 20.0 to 23.0 feet to account for wave runup and wave overtopping. At the periphery, the top elevations of the dikes gradually slope downward to 17 feet on the western side and 18 feet on the eastern side to meet existing terrain. The top elevation of the Fairhaven Dike is 20.0 feet.

The technology of the 1950's limited the number of hurricane tracks that could realistically be simulated to determine the worst case hurricane flooding scenario for the design of the barrier. The technology of the late 1980's enabled the SLOSH model to simulate a total of 536 hypothetical hurricanes for the Narragansett Bay/Buzzards Bay SLOSH basin, and thus calculate worst case surge estimates for all locations within that basin.

A review of the storm surge data calculated by the SLOSH model indicates that peak surges generated from categories 3 and 4 hurricanes, with forward speeds greater than 40 mph, may exceed the barrier's design elevation. Hurricanes that exceed the barrier's design height approach on critical storm tracks and make landfall coincident with high astronomical tide. Worst case category 3 hurricanes traveling at forward speeds of 40 mph may generate stillwater elevations up to 16.4 feet at high tide. Up to a 20.8 foot stillwater elevation is possible if a worst case category 3 hurricane accelerates to 60 mph. During a category 4 hurricane, surges as great as 19.5 feet and 24.1 feet are possible at forward speeds of 40 mph and 60 mph, respectively.

These scenarios assume that the hurricanes travel on a north-northwest to north-northeast track direction, peak surge arrives coincident with predicted mean high tide, and the storm landfalls at the critical location to produce the highest level of storm surge at New Bedford. It is extremely unlikely that all critical meteorological and hydrological conditions will occur simultaneously at New Bedford, however, State and local officials should have a complete understanding of the public's potential risk should a storm of this nature be forecasted.

The scope and nature of hurricane evacuation studies justifies quantifying the amount of flooding even from those storms with only a remote possibility of occurring. Therefore, the inundation maps developed for the communities of New Bedford, Fairhaven, and Acushnet (see Plates I-8, I-9, and I-10 of the companion <u>Inundation Map Atlas</u>), delineate "worst case" flood limits behind the barrier should it be overtopped or become inoperable. The officials and public in the communities involved should be assured that areas behind the barrier are protected from the majority of expected hurricanes. On the inundation maps, land areas protected by the barrier are delineated using a separate designation to reflect the most extreme flood condition.

For purposes of this study, it was assumed that the areas located behind the barrier would be evacuated in response to the worst case scenarios outlined above. Accordingly, evacuation maps for the affected communities (see Plates E-8, E-9, and E-10 of the companion <u>Evacuation Map Atlas</u>) identify separate evacuation zones behind the barrier. Also, the results of study analyses within this report have been segregated to account for these special areas.

As a hurricane approaches the region, State and local emergency management officials should coordinate directly with the National Weather Service Meteorologist In-Charge for hurricane surge forecasts and astronomical tide conditions at the barrier. It is important that officials recognize that the project's design stillwater elevation is 16.0 feet NGVD, and the minimum top elevation of the project is 17.0 feet NGVD. Therefore, evacuation of areas behind the project is recommended should the National Weather Service storm tide forecasts exceed the project's minimum top elevation.

2.5.8 Freshwater Flooding

Most of the loss of human life and property in hurricanes has been due to storm surge flooding. This study develops estimates of potential hurricane surge heights, and delineates those areas on maps for evacuation planning. While it is recognized that rainfall accompanying a hurricane can cause significant flooding of low-lying areas, it is difficult to predict the amount or timing of rainfall associated with hurricanes. For most hurricanes, the heaviest rainfall begins near the time of arrival of sustained gale-force winds; however, excessive rainfall can precede an approaching hurricane by as much as 24 hours. Unrelated weather systems can also contribute significant rainfall amounts within a basin in advance of a hurricane. Another phenomenon was observed with Hurricane Lili in late October 1996. Although Lili did not strike New England, it funneled significant amounts of moisture into a low pressure system which was spinning over New England, causing substantial flooding.

Due to the inability to accurately predict rainfall amounts from an approaching hurricane, no attempt was made to predict flooding from hurricane rainfall. It is recommended that emergency management officials use the FEMA Flood Insurance Study and Flood Insurance Rate Maps for their community as a guide to the possible extent of freshwater flooding. The maps provide a good indication of areas which may need to be evacuated due to fresh water flooding. The maps are based on historical data, and include such extreme events as the August 1955 flooding associated with Hurricane Diane. The sudden and torrential rains of Hurricane Diane fell on ground already saturated by the rains of Hurricane Connie one week earlier, causing some of the most severe flooding in New England history.

Chapter Three

VULNERABILITY ANALYSIS

3.1 PURPOSE

The primary purpose of the vulnerability analysis is to identify the areas, populations, and facilities which are vulnerable to storm surge flooding associated with hurricanes. Storm surge data from the Hazards Analysis was used to map inundation areas; to determine evacuation zones and evacuation scenarios; to quantify the population at risk considering a range of hurricane intensities; and to identify major medical/ institutional facilities and mobile home/trailer parks and major campgrounds in each community.

Mobile homes are the only housing type vulnerable to hurricane winds specifically addressed in the analysis. These structures are particularly susceptible to damage from winds, therefore the names and locations of mobile home parks and trailer parks are given. No attempt was made to identify other housing types that may be vulnerable to wind damage.

3.2 INUNDATION MAP ATLAS

Areas potentially subject to tidal flooding from hurricanes of various meteorological scenarios are presented for each community in the companion Southern Massachusetts Hurricane Evacuation Study, Inundation Map Atlas, December 1994. The flood limits delineated on each map were determined directly from surge profiles (see Plates ii and iii of the Atlas) developed from the Hazard Analysis discussed in the previous chapter. For each coastal community, the atlas groups the worst case storm tides possible from hurricanes of varying forward speed and intensity into three surge inundation areas which correspond to specific elevations relative to NGVD 1929. A particular hurricane scenario (determined by the hurricane's forward speed and intensity) may be related to an appropriate inundation area from a unique "Inundation Matrix" shown on each community's map sheet. Land areas with elevations equal to or lower than the storm tide elevations given in the Atlas's profiles were delineated on Massachusetts Department of Public Works General Highway Maps. To graphically represent the land areas that can be affected by hurricane surge, storm tide elevations were mapped by interpolating between the 10-foot contour elevations provided by the United States Geological Survey's (USGS) 7.5 minute series quadrangle maps.

3.3 EVACUATION MAP ATLAS

Evacuation zones which correspond to the inundation areas delineated by the Inundation Map Atlas are presented in a second companion atlas entitled the Southern Massachusetts Hurricane Evacuation Study, Evacuation Map Atlas, April 1997. The maps of this atlas serve two primary purposes. First, for each community they identify land areas (evacuation zones) vulnerable to hurricane surge which should be considered for evacuation prior to a hurricane's landfall. Second, the facility names and map locations of public shelters, medical/institutional facilities, mobile home/trailer parks and major campgrounds are shown. The information is provided to assist local officials in recognizing those locations most at risk from hurricanes, and to identify public shelters, and other facilities of importance that may require special provisions during evacuation proceedings.

Two evacuation zones are presented for twelve possible hurricane scenarios that vary by a hurricane's forward speed and intensity. An "Evacuation Matrix", which is analogous to the "Inundation Matrix" developed in the Inundation Map Atlas, is provided for each community to relate an appropriate evacuation zone for the approaching storm. The first evacuation zone (closest to the shore) has been termed "Evacuation Area A". It generally corresponds to the less severe hurricanes in terms of storm surge flooding potential. Likewise, the second evacuation zone (further inland away from the shore) is termed "Evacuation Area B". This evacuation zone corresponds to those hurricanes that can cause the most severe surge flooding. For purposes of this study, hurricanes corresponding to "Evacuation Area A" and "Evacuation Area B" have been classified as belonging to a "weak hurricane scenario" and a "severe hurricane scenario", respectively.

The extent of land area included within each evacuation zone is based on the surge inundation areas shown in the Inundation Map Atlas. Evacuation zones encompass all potentially inundated land areas as well as "pockets" of land that could be isolated by surrounding surge. The evacuation maps were coordinated with local officials in draft form to ensure that local perspectives on the delineation of evacuation zones were included in the Atlas. It was attempted to use identifiable geographic features such as streets to delineate the evacuation zone boundaries. This was done so that officials could easily convey to the public which areas should be evacuated. However, in some cases using streets as the evacuation zone boundaries would have resulted in overly-extensive evacuation zones. In those cases, the evacuation zone boundaries were kept closer to the inundation zone boundaries.

3.4 VULNERABLE POPULATION

The permanent and seasonal residents of each community were included when estimating the total population living within the evacuation zones. For the study communities in Barnstable, Bristol, and Plymouth Counties, the permanent population was determined from 1990 census information. For Dukes County, the permanent population of each community was obtained from the Martha's Vineyard Commission and represented the 1995 permanent population. The permanent population of Nantucket was obtained from the Director of Nantucket Emergency Management, and also represented the 1995 permanent population.

Seasonal residents consist of those people whose permanent residences are elsewhere, but who relocate to housing units on a temporary basis for some time during the year. The census classifies housing units used by this population type as "vacant housing units for seasonal, recreational, or occasional use". The study assumed that housing units classified by the census as such may be used to estimate the long-term seasonal population.

For the study communities in Bristol and Plymouth Counties except Wareham, the study assumed that seasonal houses had the same occupancy rate as permanently occupied houses in each community. For the study communities in Barnstable County and the Town of Wareham in Plymouth County, it was assumed that seasonal houses had an occupancy rate of 6 persons per seasonal house. That figure was based on a report published by the Cape Cod Commission, and on discussions with the Massachusetts Emergency Management Agency and local officials. For Dukes County, the seasonal population of each community was obtained from the Martha's Vineyard Commission and represented the 1995 seasonal population. The seasonal population of Nantucket was determined through discussions with the Director of Nantucket Emergency Management.

The study did not explicitly attempt to quantify seasonal residents occupying hotels, motels, and campgrounds on a less permanent basis, or to determine the number of "day-trippers" visiting a particular location. The behavior and effects of "day trippers" on the total evacuation is discussed in more detail in the Behavioral Analysis (Appendix B) and Transportation Analysis (Appendix C).

Tables 3.1 and **3.2** give estimates, by community, of the potentially vulnerable population by tabulating the total number of permanent and seasonal residents living within Evacuation Area A (weak storm scenario) and Evacuation Area B (severe storm scenario) shown in the Evacuation Map Atlas. The vulnerable population estimates also include the estimated mobile home population of each community because of their particular susceptibility to hurricane winds. The mobile home population was estimated by assuming an occupancy rate of 2 persons per mobile home for each mobile home listed in the 1990 census. The mobile home population includes those people living in organized mobile home/trailer park facilities as well as those residing on separate parcels of land.

TABLE 3.1(a)
BARNSTABLE COUNTY
VULNERABLE POPULATION
WEAK HURRICANE SCENARIO

Community	Population of Town			Vulnerable Population			
	Permanent [1]	Seasonal	Total	Permanent	Seasonal	Mobile Home	Total
Barnstable	40,950	28,780	69,730	5,170	3,800	20	8,990
Bourne	16,060	13,120	29,180	6,970	4,830	180	11,980
Brewster	8,440	16,510	24,950	570	1,000	20	1,590
Chatham	6,580	16,490	23,070	1,860	3,960	0	5,820
Dennis	13,860	42,070	55,930	4,320	13,980	170	18,470
Eastham	4,460	15,930	20,390	850	2,590	0	3,440
Falmouth	27,960	33,760	61,720	11,700	12,950	0	24,650
Harwich	10,280	19,800	30,080	1,990	3,530	10	5,530
Mashpee	7,880	19,270	27,150	1,160	7,300	400	8,860
Orleans [2]	5,840	9,580	15,420	2,010	2,860	0	4,870
Provincetown	3,560	8,500	12,060	680	740	20	1,440
Sandwich [2]	15,490	7,220	22,710	2,490	1,780	30	4,300
Truro	1,570	8,090	9,660	230	980	10	1,220
Wellfleet	2,490	13,540	16,030	860	3,620	540	5,020
Yarmouth	21,170	28,350	49,520	5,870	4,760	210	10,840
TOTALS	186,590	281,010	467,600	46,730	68,680	1,610	117,020

NOTES:
[1] 1990 Census.
[2] Orleans and Sandwich have a single evacuation zone for all hurricane scenarios.

TABLE 3.1(b)
BRISTOL COUNTY
VULNERABLE POPULATION
WEAK HURRICANE SCENARIO

Community	Population of Town			Vulnerable Population			
	Permanent [1]	Seasonal	Total	Permanent	Seasonal	Mobile Home	Total
Acushnet [2,3]	9,550	30	9,580	0	0	600	600
Dartmouth	27,240	1,130	28,370	2,890	300	120	3,310
Fairhaven [3]	16,130	1,150	17,280	4,090	720	60	4,870
Fall River	92,700	150	92,850	1,430	10	100	1,540
New Bedford [3]	99,920	140	100,060	2,090	540	190	2,820
Rehoboth	8,660	50	8,710	370	0	10	380
Seekonk	13,050	50	13,100	290	0	0	290
Somerset [4]	17,660	50	17,710	3,690	10	0	3,700
Swansea [4]	15,410	170	15,580	5,280	60	10	5,350
Westport [4]	13,850	1,830	15,680	1,710	230	80	2,020
TOTALS	314,170	4,750	318,920	21,840	1,870	1,170	24,880

NOTES:
[1] 1990 Census.
[2] Acushnet is protected by the New Bedford Hurricane Barrier and therefore is not subject to surge flooding unless the barrier is overtopped.
[3] The New Bedford Hurricane Barrier can be overtopped by category 4 hurricanes with forward speeds of 60 MPH or greater.
[4] Somerset, Swansea, and Westport have a single evacuation zone for all hurricane scenarios.

TABLE 3.1(c)
DUKES COUNTY
VULNERABLE POPULATION
WEAK HURRICANE SCENARIO

	Population of Town			Vulnerable Population			
Community	Permanent [1]	Seasonal [1]	Total	Permanent	Seasonal	Mobile Home	Total
Chilmark	820	4,620	5,440	100	570	0	670
Edgartown	3,760	32,060	35,820	690	5,910	20	6,620
Gay Head	310	1,140	1,450	50	200	10	260
Gosnold [2]	100	600	700	100	210	0	310
Oak Bluffs	2,940	24,430	27,370	330	2,740	10	3,080
Tisbury [2]	4,330	20,560	24,890	540	2,580	30	3,150
West Tisbury	1,610	5,610	7,220	90	320	10	420
TOTALS	13,870	89,020	102,890	1,900	12,530	80	14,510

NOTES:
[1] Martha's Vineyard Commission, 1995.
[2] Gosnold and Tisbury have a single evacuation zone for all hurricane scenarios.

TABLE 3.1(d)
NANTUCKET COUNTY
VULNERABLE POPULATION
WEAK HURRICANE SCENARIO

Community	Population of Town			Vulnerable Population			
	Permanent [1]	Seasonal [1]	Total	Permanent	Seasonal	Mobile Home	Total
Nantucket [2]	8,500	36,290	44,790	1,630	9,890	0	11,520

NOTES:
[1] Per Director of Nantucket Emergency Management.
[2] Nantucket has a single evacuation zone for all hurricane scenarios.

TABLE 3.1(e)
PLYMOUTH COUNTY
VULNERABLE POPULATION
WEAK HURRICANE SCENARIO

	Population of Town			Vulnerable Population			
Community	Permanent [1]	Seasonal	Total	Permanent	Seasonal	Mobile Home	Total
Marion	4,500	1,130	5,630	3,970	1,000	0	4,970
Mattapoisett	5,850	1,650	7,500	4,060	1,140	20	5,220
Rochester	3,920	110	4,030	130	0	10	140
Wareham	19,230	18,800	38,030	14,030	11,100	2,190	27,320
TOTALS	33,500	21,690	55,190	22,190	13,240	2,220	37,650

NOTES:
[1] 1990 Census.

TABLE 3.2(a)
BARNSTABLE COUNTY
VULNERABLE POPULATION
SEVERE HURRICANE SCENARIO

Community	Population of Town			Vulnerable Population			
	Permanent [1]	Seasonal	Total	Permanent	Seasonal	Mobile Home	Total
Barnstable	40,950	28,780	69,730	6,220	4,790	20	11,030
Bourne	16,060	13,120	29,180	7,800	4,830	180	12,810
Brewster	8,440	16,510	24,950	1,050	1,850	20	2,920
Chatham	6,580	16,490	23,070	2,140	4,570	0	6,710
Dennis	13,860	42,070	55,930	6,000	18,850	170	25,020
Eastham	4,460	15,930	20,390	1,380	4,060	0	5,440
Falmouth	27,960	33,760	61,720	14,220	14,280	0	28,500
Harwich	10,280	19,800	30,080	3,470	6,540	10	10,020
Mashpee	7,880	19,270	27,150	1,420	8,050	400	9,870
Orleans [2]	5,840	9,580	15,420	2,010	2,860	0	4,870
Provincetown	3,560	8,500	12,060	2,200	2,570	20	4,790
Sandwich [2]	15,490	7,220	22,710	2,490	1,780	30	4,300
Truro	1,570	8,090	9,660	240	1,020	10	1,270
Wellfleet	2,490	13,540	16,030	1,500	5,970	540	8,010
Yarmouth	21,170	28,350	49,520	10,670	9,720	210	20,600
TOTALS	186,590	281,010	467,600	62,810	91,740	1,610	156,160

NOTES:
[1] 1990 Census.
[2] Orleans and Sandwich have a single evacuation zone for all hurricane scenarios.

TABLE 3.2(b)
BRISTOL COUNTY
VULNERABLE POPULATION
SEVERE HURRICANE SCENARIO

Community	Population of Town			Vulnerable Population			
	Permanent [1]	Seasonal	Total	Permanent	Seasonal	Mobile Home	Total
Acushnet [2,3]	9,550	30	9,580	900	0	600	1,500
Dartmouth	27,240	1,130	28,370	3,220	340	120	3,680
Fairhaven [3]	16,130	1,150	17,280	11,340	990	60	12,390
Fall River	92,700	150	92,850	4,840	10	100	4,950
New Bedford [3]	99,920	140	100,060	19,660	550	190	20,400
Rehoboth	8,660	50	8,710	640	10	10	660
Seekonk	13,050	50	13,100	530	0	0	530
Somerset [4]	17,660	50	17,710	3,690	10	0	3,700
Swansea [4]	15,410	170	15,580	5,280	60	10	5,350
Westport [4]	13,850	1,830	15,680	1,710	230	80	2,020
TOTALS	314,170	4,750	318,920	51,810	2,200	1,170	55,180

NOTES:
[1] 1990 Census.
[2] Acushnet is protected by the New Bedford Hurricane Barrier and therefore is not subject to surge flooding unless the barrier is overtopped.
[3] The New Bedford Hurricane Barrier can be overtopped by category 4 hurricanes with forward speeds of 60 MPH or greater.
[4] Somerset, Swansea, and Westport have a single evacuation zone for all hurricane scenarios.

TABLE 3.2(c)
DUKES COUNTY
VULNERABLE POPULATION
SEVERE HURRICANE SCENARIO

Community	Population of Town			Vulnerable Population			
	Permanent [1]	Seasonal [1]	Total	Permanent	Seasonal	Mobile Home	Total
Chilmark	820	4,620	5,440	190	1,070	0	1,260
Edgartown	3,760	32,060	35,820	1,330	11,360	20	12,710
Gay Head	310	1,140	1,450	70	240	10	320
Gosnold [2]	100	600	700	100	210	0	310
Oak Bluffs	2,940	24,430	27,370	750	6,220	10	6,980
Tisbury [2]	4,330	20,560	24,890	540	2,580	30	3,150
West Tisbury	1,610	5,610	7,220	240	820	10	1,070
TOTALS	13,870	89,020	102,890	3,220	22,500	80	25,800

NOTES:
[1] Martha's Vineyard Commission, 1995.
[2] Gosnold and Tisbury have a single evacuation zone for all hurricane scenarios.

TABLE 3.2(d)
NANTUCKET COUNTY
VULNERABLE POPULATION
SEVERE HURRICANE SCENARIO

	Population of Town			Vulnerable Population			
Community	Permanent [1]	Seasonal [1]	Total	Permanent	Seasonal	Mobile Home	Total
Nantucket [2]	8,500	36,290	44,790	1,630	9,890	0	11,520

NOTES:
[1] Per Director of Nantucket Emergency Management.
[2] Nantucket has a single evacuation zone for all hurricane scenarios.

TABLE 3.2(e)
PLYMOUTH COUNTY
VULNERABLE POPULATION
SEVERE HURRICANE SCENARIO

	Population of Town			Vulnerable Population			
Community	Permanent [1]	Seasonal	Total	Permanent	Seasonal	Mobile Home	Total
Marion	4,500	1,130	5,630	4,500	1,130	0	5,630
Mattapoisett	5,850	1,650	7,500	4,780	1,340	20	6,140
Rochester	3,920	110	4,030	290	10	10	310
Wareham	19,230	18,800	38,030	14,170	11,220	2,190	27,580
TOTALS	33,500	21,690	55,190	23,740	13,700	2,220	39,660

NOTES:
[1] 1990 Census.

3.5 MEDICAL/INSTITUTIONAL FACILITIES

Inventories of major medical/institutional facilities in each community were compiled and are listed in **Tables 3.3(a)** through **3.3(e)** by county. Facility lists are organized in the order that community maps appear in the Evacuation Map Atlas. The location of each facility can be found by cross referencing its map key numbers with the locator symbols shown in the Atlas for a particular community. Medical and institutional facilities located within evacuation zones may require special evacuation provisions and perhaps some additional lead time prior to actual evacuations. Other medical and institutional facilities located outside of evacuation zones are included in the tables and shown on the maps as alternative comparable care facilities for evacuated patients. Building names and locations for all facilities in the tables were provided by emergency management officials in each community. Unless otherwise noted, "None", in the column labeled "SURGE FLOODING" in **Tables 3.3(a)** through **3.3(e)** indicates the facility is not located within a hurricane surge area. No attempt has been made to determine whether or not a particular facility is located within the 100- or 500-year flood plain delineations of FEMA's Flood Insurance Rate Maps.

TABLE 3.3(a)
BARNSTABLE COUNTY
MEDICAL & INSTITUTIONAL FACILITIES

MAP KEY[1]	COMMUNITY	FACILITY NAME	TYPE	SURGE FLOODING[2,3]
1	Barnstable	Cape Cod Hospital	Med.	Yes
2	Barnstable	Fraser Rest Home of Hyannis	Nurs.	Yes
3	Barnstable	Lewis Bay Convalescent Home	Nurs.	None
4	Barnstable	Whitehall Health Care Facility	Nurs.	None
5	Barnstable	Whitehall Pavilion Nursing Home	Nurs.	None
6	Barnstable	Cape Regency Nursing Home	Nurs.	None
1	Bourne	Barnstable County Hospital	Med.	None
2	Bourne	Cape Cod Nursing and Retirement Home	Nurs.	Yes
3	Bourne	Bourne Manor	Nurs.	None
1	Brewster	Fire Station & Police Station	Med.	None
2	Brewster	Brewster Manor	Med.	None
3	Brewster	Medi-Center 5 (Harwich)	Med.	None
4	Brewster	Brewster Medical Associates	Med.	None
5	Brewster	Orleans Medical Center	Med.	None
6	Brewster	Brewster Manor Nursing Home	Nurs.	None
7	Brewster	Pleasant Bay Nursing Home	Nurs.	None
1	Chatham	Liberty Commons Nursing Home	Nurs.	None
1	Dennis	Cape Cod Medical Center	Med.	None
2	Dennis	Eagle Pond Nursing Home	Nurs.	None
	Eastham	None		
1	Falmouth	Falmouth Hospital	Med.	None
2	Falmouth	Fraser Nursing Home of Falmouth	Nurs.	None
3	Falmouth	Falmouth Nursing Home	Nurs.	Yes

NOTES:
[1] Facility locations are provided in the companion Evacuation Map Atlas.
[2] "None" indicates facility is not located within hurricane surge areas.
[3] "Yes" indicates facility is located in or adjacent to hurricane surge areas.

TABLE 3.3(a) (continued)
BARNSTABLE COUNTY
MEDICAL & INSTITUTIONAL FACILITIES

MAP KEY[1]	COMMUNITY	FACILITY NAME	TYPE	SURGE FLOODING[2,3]
4	Falmouth	Royal Megansett Nursing Home	Nurs.	None
5	Falmouth	Center for Optimum Care	Nurs.	Yes
6	Falmouth	Gosnold's Emerson House	Rehab.	Yes
7	Falmouth	Gosnold Treatment Center	Rehab.	None
8	Falmouth	J.M.L. Care Center	Nurs.	None
9	Falmouth	Heritage at Falmouth	Nurs.	None
10	Falmouth	Gosnold's Steven Miller House	Rehab.	None
1	Harwich	Medi-Center 5	Med.	None
2	Harwich	Cape Cod Regional Technical High School	Med.	None
3	Harwich	Pleasant Lake Medical Center	Med.	None
4	Harwich	Rosewood Manor Retirement Home	Nurs.	None
5	Harwich	Cranberry Pointe Nursing Home	Nurs.	None
6	Harwich	Eagle Pond Nursing Home (Dennis)	Nurs.	None
1	Mashpee	Optimum Care Nursing Home	Nurs.	None
1	Orleans	Orleans Convalescent and Retirement Home	Nurs.	None
1	Provincetown	Outer Cape Health Service	Med.	None
2	Provincetown	Provincetown Medical Group	Med.	Yes
3	Provincetown	Cape End Manor	Nurs.	None
	Sandwich	None		
	Truro	None		
1	Wellfleet	Outer Cape Health Center	Med.	None
2	Wellfleet	Wellfleet Medical Office	Med.	Yes
1	Yarmouth	Windsor Nursing and Retirement Home	Nurs.	None

NOTES:
[1] Facility locations are provided in the companion Evacuation Map Atlas.
[2] "None" indicates facility is not located within hurricane surge areas.
[3] "Yes" indicates facility is located in or adjacent to hurricane surge areas.

TABLE 3.3(b)
BRISTOL COUNTY
MEDICAL & INSTITUTIONAL FACILITIES

MAP KEY[1]	COMMUNITY	FACILITY NAME	TYPE	SURGE FLOODING[2,3]
1	Acushnet	Acushnet Nursing Home	Nurs.	None
1	Dartmouth	Dartmouth Walk-in Clinic	Med.	None
2	Dartmouth	Brandon Woods of Dartmouth	Nurs.	None
3	Dartmouth	Dartmouth Manor Rest Home	Nurs.	None
4	Dartmouth	Country Rest Home	Nurs.	None
5	Dartmouth	Harborview Manor Nursing Home	Nurs.	Yes
6	Dartmouth	Greater New Bedford Surgicenter, Inc.	Med.	None
1	Fairhaven	Nichols House Nursing Home	Nurs.	Yes
2	Fairhaven	Our Lady's Haven	Nurs.	Yes
3	Fairhaven	Alden Court	Nurs.	None
1	Fall River	Charlton Memorial Hospital	Med.	None
2	Fall River	St. Anne's Hospital	Med.	None
3	Fall River	Rose Hawthorn Lathrop Home	Nurs.	None
4	Fall River	Catholic Memorial Home	Nurs.	None
5	Fall River	Cliff Gables Nursing Home	Nurs.	None
6	Fall River	Cliff Haven Nursing Home	Nurs.	None
7	Fall River	Cliff Heights Nursing Home	Nurs.	None
8	Fall River	Cliff Lawn Nursing Home	Nurs.	None
9	Fall River	Cliff Manor Nursing Home	Nurs.	None
10	Fall River	Crawford House Convalescent Home	Nurs.	None
11	Fall River	Crestwood Convalescent Home	Nurs.	None
12	Fall River	Fall River Jewish Home for Aged	Nurs.	None
13	Fall River	Hanover House Retirement Facility	Nurs.	None

NOTES:
[1] Facility locations are provided in the companion Evacuation Map Atlas.
[2] "None" indicates facility is not located within hurricane surge areas.
[3] "Yes" indicates facility is located in or adjacent to hurricane surge areas.

TABLE 3.3(b) (continued)
BRISTOL COUNTY
MEDICAL & INSTITUTIONAL FACILITIES

MAP KEY[1]	COMMUNITY	FACILITY NAME	TYPE	SURGE FLOODING[2,3]
14	Fall River	Highland Manor Nursing Home	Nurs.	None
15	Fall River	Home for Aged People in Fall River (Adams House)	Nurs.	None
16	Fall River	Kimwell Health Care Center/Nursing Home	Nurs.	None
17	Fall River	Rosewood Rest Home	Nurs.	None
1	New Bedford	Mariner Health Care of S.E. Mass.	Nurs.	None
2	New Bedford	The Oaks Nursing Home	Nurs.	None
3	New Bedford	Mediplex Rehab Bristol	Rehab.	None
4	New Bedford	Mediplex Nursing Home	Nurs.	None
5	New Bedford	Plainview Long Term Care Facility	Rest	None
6	New Bedford	Rita's Rest Home	Rest	None
7	New Bedford	Mass. DMH Crisis Center	Emerg. Psych.	None
8	New Bedford	Kristen Beth Nursing Home	Nurs.	None
9	New Bedford	Hathaway Manor Nursing Home	Nurs.	None
10	New Bedford	Hallmark Nursing Home	Nurs./ Rehab.	None
11	New Bedford	Sacred Hearts Nursing Home	Nurs.	None
12	New Bedford	Bedford Village Nursing Home	Nurs.	None
13	New Bedford	Savoy Convalescent Home	Nurs.	None
14	New Bedford	S.E. Mass. Dialysis Clinic	Outpat. Dial.	None
15	New Bedford	Eastern Mass. Correctional Alcohol Center	Correc. Facil.	None

NOTES:
[1] Facility locations are provided in the companion Evacuation Map Atlas.
[2] "None" indicates facility is not located within hurricane surge areas.
[3] "Yes" indicates facility is located in or adjacent to hurricane surge areas.

TABLE 3.3(b) (continued)
BRISTOL COUNTY
MEDICAL & INSTITUTIONAL FACILITIES

MAP KEY[1]	COMMUNITY	FACILITY NAME	TYPE	SURGE FLOODING[2,3]
16	New Bedford	Bristol County House of Correction	Correc. Facil.	None
17	New Bedford	New Bedford Dialysis Center	Outpat. Dial.	None
18	New Bedford	Rol-Ann Rest Home	Rest	None
19	New Bedford	Havenwood Rest Home	Rest	None
20	New Bedford	Blair House	Nurs.	None
21	New Bedford	Jewish Convalescent Home	Nurs.	None
22	New Bedford	Taber Street Nursing Home	Nurs.	None
23	New Bedford	St. Luke's Hospital	Gen. Hosp.	None
	Rehoboth	None		
1	Seekonk	Route 6 Emergency Medical	Med.	None
1	Somerset	Clifton Geriatric Center	Nurs.	None
1	Swansea	Country Garden's Nursing Home	Nurs.	None
2	Swansea	Swansea Rest Home	Nurs.	None
	Westport	None		

NOTES:
[1] Facility locations are provided in the companion Evacuation Map Atlas.
[2] "None" indicates facility is not located within hurricane surge areas.
[3] "Yes" indicates facility is located in or adjacent to hurricane surge areas.

TABLE 3.3(c)
DUKES COUNTY
MEDICAL & INSTITUTIONAL FACILITIES

MAP KEY[1]	COMMUNITY	FACILITY NAME	TYPE	SURGE FLOODING[2,3]
	Chilmark	None		
1	Edgartown	Long Hill Nursing Home	Nurs.	Yes
	Gay Head	None		
	Gosnold	None		
1	Oak Bluffs	Martha's Vineyard Hospital	Med.	Yes
1	Oak Bluffs	Martha's Vineyard Hospital	Nurs.	Yes
2	Oak Bluffs	Windemere Nursing & Retirement Home	Nurs.	Yes
1	Tisbury	Henrietta Nursing House	Nurs.	Yes
	West Tisbury	None		

NOTES:
[1] Facility locations are provided in the companion Evacuation Map Atlas.
[2] "None" indicates facility is not located within hurricane surge areas.
[3] "Yes" indicates facility is located in or adjacent to hurricane surge areas.

TABLE 3.3(d)
NANTUCKET COUNTY
MEDICAL & INSTITUTIONAL FACILITIES

MAP KEY[1]	COMMUNITY	FACILITY NAME	TYPE	SURGE FLOODING[2,3]
1	Nantucket	Nantucket Cottage Hospital	Med.	None
2	Nantucket	Our Island Home	Nurs.	Yes

NOTES:
[1] Facility locations are provided in the companion Evacuation Map Atlas.
[2] "None" indicates facility is not located within hurricane surge areas.
[3] "Yes" indicates facility is located in or adjacent to hurricane surge areas.

TABLE 3.3(e)
PLYMOUTH COUNTY
MEDICAL & INSTITUTIONAL FACILITIES

MAP KEY[1]	COMMUNITY	FACILITY NAME	TYPE	SURGE FLOODING[2,3]
1	Marion	Sippican Long Term	Nurs.	Yes
1	Mattapoisett	Mattapoisett Nursing Home	Nurs.	None
	Rochester	None		
1	Wareham	Tobey Hospital	Med.	Yes
2	Wareham	Mill Brook Nursing Home	Nurs.	Yes
3	Wareham	Forestview Nursing Home	Nurs.	Yes
4	Wareham	Waterford Manor Rest Home	Nurs.	Yes
5	Wareham	Alternative Care Home	Handi.	Yes

NOTES:
[1] Facility locations are provided in the companion Evacuation Map Atlas.
[2] "None" indicates facility is not located within hurricane surge areas.
[3] "Yes" indicates facility is located in or adjacent to hurricane surge areas.

3.6 MOBILE HOME/TRAILER PARK FACILITIES

Tables 3.4(a) through **3.4(e)** list the names of mobile home and trailer parks in each community of the study area by county. Sites where a single mobile home unit may be located are not listed. However, the estimated mobile home populations listed in **Tables 3.1(a)** through **3.1(e)** include the residents of all mobile homes regardless of whether they are located in an organized park or on a separate parcel of land elsewhere in a community. All information on mobile home/trailer parks was provided by the community emergency management officials. The location of any facility listed may be found by cross referencing the map key numbers provided in the tables with the locator symbols identified in the Evacuation Map Atlas. Unless otherwise noted in the tables, "None" in the column labeled "SURGE FLOODING" indicates that a particular facility is not located within hurricane surge areas. Due to the susceptibility of these structures to high winds, it is recommended that the residents of all mobile homes, trailer parks and campgrounds be evacuated before a hurricane strikes, regardless of the flooding potential of the sites. No attempt has been made to determine whether or not a particular facility is located within the 100- or 500-year flood plain delineations of FEMA's Flood Insurance Rate Maps.

TABLE 3.4(a)
BARNSTABLE COUNTY
MOBILE HOME/TRAILER PARKS & CAMPGROUNDS

MAP KEY[1]	COMMUNITY	FACILITY NAME	TYPE[2]	SURGE FLOODING[3,4]
	Barnstable	None		
1	Bourne	Pocasset Trailer Park	TP	None
2	Bourne	Bay View Campgrounds	CG	None
3	Bourne	Bourne Scenic Park	CG	Yes
1	Brewster	Nickerson State Park	CG	None
2	Brewster	The Tent Lot	CG	None
3	Brewster	Sweet Water Forest	CG	None
4	Brewster	Shady Knoll Campground	CG	Yes
5	Brewster	Cape Cod Sea Camps	CG	None
6	Brewster	Camp Mitton	CG	None
7	Brewster	Camp Favorite	CG	None
	Chatham	None		
1	Dennis	Campers Haven	MH	Yes
2	Dennis	Grindells Trailer Park	TP	Yes
3	Dennis	Airline Mobile Trailer Park	TP	None
	Eastham	None		
1	Falmouth	Thomas Landers Campground	CG	None
2	Falmouth	Sippewissett Cabins	CG	None
	Harwich	None		
1	Mashpee	Otis Trailer Park	TP	None
2	Mashpee	Lakeside Trailer Park	TP	None
	Orleans	None		

NOTES:
[1] Facility locations are provided in the companion Evacuation Map Atlas.
[2] Mobile Home/Trailer Park or Campground.
[3] "None" indicates facility is not located within hurricane surge areas.
[4] "Yes" indicates facility is located in or adjacent to hurricane surge areas.

TABLE 3.4(a) (continued)
BARNSTABLE COUNTY
MOBILE HOME/TRAILER PARKS & CAMPGROUNDS

MAP KEY[1]	COMMUNITY	FACILITY NAME	TYPE[2]	SURGE FLOODING[3,4]
1	Provincetown	Coastal Acres	MH/TP CG	Yes
2	Provincetown	Dunes Edge	TP/CG	None
	Sandwich	None		
1	Truro	Horton's Park	TP/CG	None
2	Truro	North Truro Camp Area	TP/CG	None
3	Truro	North of Highland	CG	None
1	Wellfleet	Kendrick Shores Trailer Park	TP	Yes
2	Wellfleet	Paine's Campground	CG	None
3	Wellfleet	Massasoit Trailer Park	TP	None
4	Wellfleet	Maurice's Campground	CG	None
1	Yarmouth	Bass River Trailer Court	TP	Yes

NOTES:
[1] Facility locations are provided in the companion Evacuation Map Atlas.
[2] Mobile Home/Trailer Park or Campground.
[3] "None" indicates facility is not located within hurricane surge areas.
[4] "Yes" indicates facility is located in or adjacent to hurricane surge areas.

TABLE 3.4(b)
BRISTOL COUNTY
MOBILE HOME/TRAILER PARKS & CAMPGROUNDS

MAP KEY[1]	COMMUNITY	FACILITY NAME	TYPE[2]	SURGE FLOODING[3,4]
1	Acushnet	Acushnet Mobile Home Park	MH	None
2	Acushnet	Brookside Mobile Home Park	MH	None
3	Acushnet	South Main Street Trailer Park	TP	None
1	Dartmouth	Fenton Street	MH	None
	Fairhaven	None		
	Fall River	None		
1	New Bedford	Tripp's Trailer Park	MH/TP	None
2	New Bedford	Treasure Park	MH/TP	None
	Rehoboth	None		
	Seekonk	None		
	Somerset	None		
	Swansea	None		
	Westport	None		

NOTES:
[1] Facility locations are provided in the companion Evacuation Map Atlas.
[2] Mobile Home/Trailer Park or Campground.
[3] "None" indicates facility is not located within hurricane surge areas.
[4] "Yes" indicates facility is located in or adjacent to hurricane surge areas.

TABLE 3.4(c)
DUKES COUNTY
MOBILE HOME/TRAILER PARKS & CAMPGROUNDS

MAP KEY[1]	COMMUNITY	FACILITY NAME	TYPE[2]	SURGE FLOODING[3,4]
	Chilmark	None		
	Edgartown	None		
	Gay Head	None		
	Gosnold	None		
1	Oak Bluffs	Webbs Campground	CG	None
1	Tisbury	Martha's Vineyard Family Campground	CG	None
	West Tisbury	None		

NOTES:
[1] Facility locations are provided in the companion Evacuation Map Atlas.
[2] Mobile Home/Trailer Park or Campground.
[3] "None" indicates facility is not located within hurricane surge areas.
[4] "Yes" indicates facility is located in or adjacent to hurricane surge areas.

TABLE 3.4(d)
NANTUCKET COUNTY
MOBILE HOME/TRAILER PARKS & CAMPGROUNDS

MAP KEY[1]	COMMUNITY	FACILITY NAME	TYPE[2]	SURGE FLOODING[3,4]
	Nantucket	None		

NOTES:
[1] Facility locations are provided in the companion Evacuation Map Atlas.
[2] Mobile Home/Trailer Park or Campground.
[3] "None" indicates facility is not located within hurricane surge areas.
[4] "Yes" indicates facility is located in or adjacent to hurricane surge areas.

TABLE 3.4(e)
PLYMOUTH COUNTY
MOBILE HOME/TRAILER PARKS & CAMPGROUNDS

MAP KEY[1]	COMMUNITY	FACILITY NAME	TYPE[2]	SURGE FLOODING[3,4]
	Marion	None		
	Mattapoisett	None		
1	Rochester	Knight/Look Campground	CG	Yes
2	Rochester	Outdoor World	CG	None
1	Wareham	Royal Crest	TP	None
2	Wareham	Siesta Village	TP	None
3	Wareham	Holly Heights	TP	None
4	Wareham	Green Tree Estates	TP	None
5	Wareham	Great Hill	TP	None
6	Wareham	Ripley's	TP	Yes
7	Wareham	Garden Homes North	TP	Yes
8	Wareham	Red Wing	TP	Yes
9	Wareham	Mogan's	TP	Yes
10	Wareham	Lakeside	TP	Yes
11	Wareham	Garden Homes East	TP	Yes
12	Wareham	Garden Homes South	TP	Yes
13	Wareham	Onset Mobile Home Park	TP	Yes
14	Wareham	Maple Park Campground	CG	None

NOTES:
[1] Facility locations are provided in the companion Evacuation Map Atlas.
[2] Mobile Home, Trailer Park or Campground.
[3] "None" indicates facility is not located within hurricane surge areas.
[4] "Yes" indicates facility is located in or adjacent to hurricane surge areas.

Chapter Four

BEHAVIORAL ANALYSIS

4.1 PURPOSE

The Behavioral Analysis is intended to provide reliable planning estimates of how the public in the Study Area will respond to hurricane threats. These estimates are used in the Shelter Analysis, Transportation Analysis, and are also intended for guidance in hurricane preparedness planning and evacuation decision-making. The specific objectives of the Behavioral Analysis are to determine the following:

a. The percentage of the surge-vulnerable population that can be expected to evacuate under varying hurricane threats or in response to evacuation recommendations issued by local officials. The term "surge-vulnerable population" refers to those persons residing near the coastline, the shorelines of estuaries, or in areas of low elevation near those locations that are subjected to hurricane surge flooding.

b. The percentage of the population residing in mobile homes that will evacuate their dwellings either due to hurricane wind or water hazards.

c. The percentage of the non-surge-vulnerable population that will evacuate under varying hurricane threats. "Non-surge-vulnerable population" refers to those persons residing in areas not affected by hurricane surge flooding who evacuate due to perceived danger or wind hazards.

d. The timing at which the evacuating population will leave after being notified to evacuate.

e. The percentage of available vehicles the evacuating population will use to evacuate.

f. The percentage of the evacuating population that can be expected to utilize public shelters.

4.2 DATA SOURCES

The primary data source used for the analysis is a report entitled <u>Hurricane Evacuation Behavioral Assumptions for Massachusetts</u>, 1988. This document is part of a comprehensive analysis entitled <u>Hurricane Evacuation Behavior in the Middle Atlantic and Northeast States</u>, 1988 commissioned for use in Hurricane Evacuation Studies of eight coastal states from Virginia through Massachusetts. Both of these documents are provided in Appendix B.

Post hurricane surveys conducted after Hurricanes Gloria in 1985 and Bob in 1991 were a secondary source of response data. These data are considered to give a reliable indication of what most people at their locations are most likely to do in the future under similar hurricane threats. However, conclusions drawn from a single event may over-generalize the predicted response. Evacuation participation rates as well as many other behavior patterns can be influenced by many parameters which vary from location to location. For this reason, no conclusive behavioral assumptions in this analysis have been drawn solely from post hurricane studies. Instead, assumptions were based on a "general response model" and compared with actual data for verification.

Other data sources used in this analysis are Hurricane Evacuation Studies currently in place in other States. In many states, these studies were tested and shown to be valid when actual evacuations in response to real events were successfully conducted. Observed behavioral responses during actual evacuations which compared favorably to predicted data were heavily weighted when developing similar predictions of behavioral response for Massachusetts.

4.3 GENERAL RESPONSE MODEL

Most of the behavioral assumptions derived for Corps of Engineers and FEMA-sponsored hurricane evacuation studies have been formulated using a "general response model." The concept of the General Response Model for hurricane evacuation studies was developed by Hazard's Management Group, Inc. It is based on data derived from an extensive list of post hurricane response studies conducted nationwide over the last three decades. Relationships between response and various parameters affecting response (such as risk area, actions by officials, time of day, threat level, etc.) were inputs into the model. Understanding how response varies with population characteristics and evacuation circumstances enables one to predict hurricane evacuation response by analyzing the characteristics of the study area. This is true whether or not the location under investigation has experienced a hurricane in the past. Once the General Response Model is applied to a study area, the Model's predicted values may be validated by comparing them with patterns observed in actual and hypothetical response data collected in the study area.

One main feature in applying the General Response Model in support of Corps' and FEMA's hurricane evacuation studies was a survey of the response to Hurricane Gloria by threatened populations of eight states along the eastern seaboard. Surveys included questions pertaining to the actions taken by people during Gloria's evacuation, as well as questions of intended actions during hypothetical evacuations. Criteria for selecting survey locations varied from state to state, but in most instances the locations were chosen because they were representative of other areas within that state. A total of approximately 2,000 samples at both "beach" and "mainland" areas were taken across the eight states.

The Massachusetts portion of the sample survey was conducted by telephone. After consultation with State emergency management officials in Massachusetts, a telephone survey of 100 coastal residents was designed. Households in Massachusetts that were interviewed were from the town of Wareham. Tabulated responses are given in Appendix B.

4.4 BEHAVIORAL ASSUMPTIONS

It is important to recognize that no single set of behavioral assumptions is appropriate throughout the entire coastal area of Massachusetts. The eight state survey conducted after Hurricane Gloria showed that response may vary even within relatively small geographical areas. Furthermore, behavior during the next hurricane threat might be quite different from that observed in Gloria. Fortunately, such variations can generally be predicted. Response patterns observed in Massachusetts during Gloria were very consistent with the General Response Model developed after studying public response in many hurricane evacuations throughout the east and Gulf coasts of the United States over the past three decades.

The following paragraphs address each of the objectives established for the Behavioral Analysis and present generalized results for each objective. This information is used in later chapters to establish appropriate behavioral assumptions for the Shelter and Transportation Analyses.

4.4.1 Evacuation Participation Rates

There are two overriding factors that influence whether or not residents will evacuate: actions by public officials, and the perceived degree of hazard at the location of interest. Behavioral analyses have shown that in the face of a severe hurricane, about 90 percent of residents in flood-prone areas near the open coast will evacuate if public officials take aggressive action urging or ordering them to leave. In the same areas, about 80 percent of residents will evacuate if they perceive the hurricane threat as not severe. Evacuation participation among those living along inland areas less vulnerable to hurricane surge is expected to be about 40 to 80 percent, depending on the public's perceived danger and the storm's severity.

Participation rates of this magnitude will result only if officials are successful in communicating the urgency of evacuation messages. One method to ensure that messages reach the intended audience is to supplement television and radio announcements with police or other officials issuing warnings door-to-door or by loudspeakers. In post hurricane studies, door-to-door notification methods have shown to be the most reliable because residents of particular households understand that evacuation notices are directed at them. Less aggressive or unsuccessful dissemination of evacuation notices will likely result in evacuation rates closer to 55 to 65 percent in open coast areas and 30 percent or less in vulnerable inland areas.

Mobile home residents, regardless of where they reside in a community, are more likely to evacuate than people who live in more substantial dwelling units. This is particularly true if officials specifically encourage their evacuation. The willingness of mobile home residents to evacuate is generally not dependent on storm severity because of their vulnerability to hurricane winds of even the weakest storms. About 55 to 100 percent of mobile home residents can be expected to evacuate if encouraged to do so by officials, depending on their location relative to the coast.

Depending upon how severe a hurricane is and how widely the hurricane threat is broadcasted, a small group of people will always evacuate even when not specifically recommended to do so. Hurricane Evacuation Studies of other states tested during recent hurricanes have shown that as much as 5 percent of the "non-surge vulnerable population" in the vicinity of the evacuation will also evacuate. Although no specific behavioral data was collected in New England with regard to this statistic, it is reasonable to assume that evacuation by the "non-surge vulnerable population" in New England will be no greater than that at other locations in the United States. Most year-round homes in New England have protective subsurface foundations which offer residents in fear of hurricane winds a safe place of refuge. On grade, or slab, construction more typical of temperate climates do not offer residents this same security. People living in this type of housing unit are more vulnerable to wind hazards and therefore are more likely to evacuate.

The tendency for tourists to evacuate depends on their intended length of stay and how far they traveled from their homes. The group composed of those who own or rent summer homes and stay most of the summer respond to evacuation recommendations much the same as permanent residents would. Tourists who rent for shorter periods of time tend to evacuate at slightly greater rates of 85 to 95 percent depending on storm severity. These people most often vacation at beachfront or nearby locations of greater risk which results in increased participation rates if informed of their vulnerability by officials. "Day-trippers" (i.e., nearby residents who visit the coast during the day and return home in the evening) present no special evacuation problems, since most will stay home in response to forecasts of deteriorating weather. Visits by day-trippers will be even further reduced if officials actively discourage such visits through news media announcements.

Disseminating evacuation recommendations to tourists may be difficult because many do not watch television or listen to radio broadcasts regularly. It may be necessary for officials to get word directly to hotels, motels, and rental properties that an evacuation has been recommended. Vacationers, particularly campers with travel trailers, tend to rely upon hotel/motel or campground managers for advice. Facility managers should encourage tourists who are already in planned evacuation zones to return home early, and encourage tourists with reservations who have not yet arrived to stay home until the threat has passed. For those tourists who choose instead to "ride out the storm," it is important that emergency management officials have the cooperation of facility managers in order to ensure that these guests receive appropriate advice.

At coordination meetings held with State and local officials, some local officials expressed concern that participation rates appear higher than they observed in past evacuations and are higher than they would expect to observe under future threats. The willingness of people to evacuate is directly related to how aggressively officials encourage them to leave. Behavioral studies have shown that participation rates will decrease as much as 25 to 50 percent in areas where residents fail to hear officials' recommendations. After consultation with State and local emergency management officials at subsequent coordination meetings, it was decided that the evacuation participation rates shown in **Table 4.1** would be used.

It is recognized that the evacuation rates in **Table 4.1** may not fully represent the complex evacuation situations of Martha's Vineyard, Nantucket, and Gosnold. The Steamship Authority shuts down ferry service when weather conditions jeopardize operations.[1] All people desiring to evacuate the islands may not be able to do so. This was observed during the evacuation prior to Hurricane Edouard over Labor Day weekend. These factors are difficult to figure into an evacuation analysis. Therefore, the rates shown in **Table 4.1** were used to estimate the number of evacuees from Martha's Vineyard, Nantucket, and Gosnold as well.

TABLE 4.1
EVACUATION PARTICIPATION RATES

EVACUATION SCENARIO[1]	EVACUATION AREA "A"[2]	EVACUATION AREA "B"[3]	MOBILE HOME RESIDENTS	NON-SURGE VULNERABLE POPULATION[4]
Weak Storm	80 %	40 %	100 %	2 %
Severe Storm	90 %	90 %	100 %	5 %

Notes:
[1] Descriptions of "weak storm" and "severe storm" scenarios are given on page 3-2.
[2] Evacuation zones closest to the coast as shown in the Evacuation Map Atlas.
[3] Evacuation zones farthest from the coast as shown in the Evacuation Map Atlas.
[4] Percentage of the total community's "non-surge vulnerable population" assumed to evacuate.

Tables 4.2 and **4.3** list the estimated number of permanent and seasonal persons that can be expected to evacuate their homes for a given hurricane threat. **Table 4.2** refers to evacuations for a weak hurricane scenario, and **Table 4.3** refers to evacuations for a severe hurricane scenario. Estimates of the evacuating population were made by applying evacuation participation rates shown in **Table 4.1** to the vulnerable population data shown in **Tables 3.1** and **3.2**.

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[1]The Steamship Authority and the Massachusetts Emergency Management Agency are currently developing a contingency plan for natural disasters.

TABLE 4.2(a)
BARNSTABLE COUNTY
EVACUATING POPULATION
WEAK HURRICANE SCENARIO

Community	Population of Town			Evacuating Population			
	Permanent	Seasonal	Total	Surge Areas	Non-Surge Areas	Mobile Homes	Total
Barnstable	40,950	28,780	69,730	7,990	1,170	20	9,180
Bourne	16,060	13,120	29,180	9,770	330	180	10,280
Brewster	8,440	16,510	24,950	1,790	440	20	2,250
Chatham	6,580	16,490	23,070	5,010	330	0	5,340
Dennis	13,860	42,070	55,930	17,260	620	170	18,050
Eastham	4,460	15,930	20,390	3,550	300	0	3,850
Falmouth	27,960	33,760	61,720	21,260	660	0	21,920
Harwich	10,280	19,800	30,080	6,210	400	10	6,620
Mashpee	7,880	19,270	27,150	7,170	350	400	7,920
Orleans [1]	5,840	9,580	15,420	3,890	210	0	4,100
Provincetown	3,560	8,500	12,060	2,470	150	20	2,640
Sandwich [1]	15,490	7,220	22,710	3,420	370	30	3,820
Truro	1,570	8,090	9,660	990	170	10	1,170
Wellfleet	2,490	13,540	16,030	4,780	160	540	5,480
Yarmouth	21,170	28,350	49,520	12,410	580	210	13,200
TOTALS	186,590	281,010	467,600	107,970	6,240	1,610	115,820

NOTES:
[1] Orleans and Sandwich have a single evacuation zone for all hurricane scenarios.

TABLE 4.2(b)
BRISTOL COUNTY
EVACUATING POPULATION
WEAK HURRICANE SCENARIO

Community	Population of Town			Evacuating Population			
	Permanent	Seasonal	Total	Surge Areas	Non-Surge Areas	Mobile Homes	Total
Acushnet [1,2]	9,550	30	9,580	0	160	600	760
Dartmouth	27,240	1,130	28,370	2,700	490	120	3,310
Fairhaven [2]	16,130	1,150	17,280	3,850	100	60	4,010
Fall River	92,700	150	92,850	2,520	1,760	100	4,380
New Bedford [2]	99,920	140	100,060	2,790	960	90	3,840
Rehoboth	8,660	50	8,710	410	160	10	580
Seekonk	13,050	50	13,100	330	250	0	580
Somerset [3]	17,660	50	17,710	2,960	280	0	3,240
Swansea [3]	15,410	170	15,580	4,270	210	10	4,490
Westport [3]	13,850	1,830	15,680	1,550	270	80	1,900
TOTALS	314,170	4,750	318,920	21,380	4,640	1,070	27,090

NOTES:
[1] Acushnet is protected by the New Bedford Hurricane Barrier and therefore is not subject to surge flooding unless the barrier is overtopped.
[2] The New Bedford Hurricane Hurricane Barrier can be overtopped by category 4 hurricanes with forward speeds of 60 MPH or greater.
[3] Somerset, Swansea, and Westport have a single evacuation zone for all hurricane scenarios.

TABLE 4.2(c)
DUKES COUNTY
EVACUATING POPULATION
WEAK HURRICANE SCENARIO

Community	Population of Town			Evacuating Population			
	Permanent	Seasonal	Total	Surge Areas	Non-Surge Areas	Mobile Homes	Total
Chilmark	820	4,620	5,440	770	80	0	850
Edgartown	3,760	32,060	35,820	7,720	460	20	8,200
Gay Head	310	1,140	1,450	230	20	10	260
Gosnold [1]	100	600	700	270	10	0	280
Oak Bluffs	2,940	24,430	27,370	4,020	410	10	4,440
Tisbury [1]	4,330	20,560	24,890	2,500	440	30	2,970
West Tisbury	1,610	5,610	7,220	580	120	10	710
TOTALS	13,870	89,020	102,890	16,090	1,540	80	17,710

NOTES:
[1] Gosnold and Tisbury have a single evacuation zone for all hurricane scenarios.

TABLE 4.2(d)
NANTUCKET COUNTY
EVACUATING POPULATION
WEAK HURRICANE SCENARIO

Community	Population of Town			Evacuating Population			
	Permanent	Seasonal	Total	Surge Areas	Non-Surge Areas	Mobile Homes	Total
Nantucket [1]	8,500	36,290	44,790	9,940	670	0	10,610

NOTES:
[1] Nantucket has a single evacuation zone for all hurricane scenarios.

TABLE 4.2(e)
PLYMOUTH COUNTY
EVACUATING POPULATION
WEAK HURRICANE SCENARIO

Community	Population of Town			Evacuating Population			
	Permanent	Seasonal	Total	Surge Areas	Non-Surge Areas	Mobile Homes	Total
Marion	4,500	1,130	5,630	4,250	0	0	4,250
Mattapoisett	5,850	1,650	7,500	4,530	30	20	4,580
Rochester	3,920	110	4,030	170	80	10	260
Wareham	19,230	18,800	38,030	20,210	210	2,190	22,610
TOTALS	33,500	21,690	55,190	29,160	320	2,220	31,700

TABLE 4.3(a)
BARNSTABLE COUNTY
EVACUATING POPULATION
SEVERE HURRICANE SCENARIO

Community	Population of Town			Evacuating Population			
	Permanent	Seasonal	Total	Surge Areas	Non-Surge Areas	Mobile Homes	Total
Barnstable	40,950	28,780	69,730	9,900	2,930	20	12,850
Bourne	16,060	13,120	29,180	11,360	820	180	12,360
Brewster	8,440	16,510	24,950	2,610	1,100	20	3,730
Chatham	6,580	16,490	23,070	6,030	820	0	6,850
Dennis	13,860	42,070	55,930	22,360	1,550	170	24,080
Eastham	4,460	15,930	20,390	4,900	750	0	5,650
Falmouth	27,960	33,760	61,720	25,650	1,660	0	27,310
Harwich	10,280	19,800	30,080	9,010	1,000	10	10,020
Mashpee	7,880	19,270	27,150	8,520	860	400	9,780
Orleans [1]	5,840	9,580	15,420	4,380	530	0	4,910
Provincetown	3,560	8,500	12,060	4,290	360	20	4,670
Sandwich [1]	15,490	7,220	22,710	3,840	920	30	4,790
Truro	1,570	8,090	9,660	1,130	420	10	1,560
Wellfleet	2,490	13,540	16,030	6,720	400	540	7,660
Yarmouth	21,170	28,350	49,520	18,350	1,450	210	20,010
TOTALS	186,590	281,010	467,600	139,050	15,570	1,610	156,230

NOTES:

[1] Orleans and Sandwich have a single evacuation zone for all hurricane scenarios.

TABLE 4.3(b)
BRISTOL COUNTY
EVACUATING POPULATION
SEVERE HURRICANE SCENARIO

Community	Population of Town			Evacuating Population			
	Permanent	Seasonal	Total	Surge Areas	Non-Surge Areas	Mobile Homes	Total
Acushnet [1,2]	9,550	30	9,580	820	400	600	1,820
Dartmouth	27,240	1,130	28,370	3,200	1,240	120	4,560
Fairhaven [2]	16,130	1,150	17,280	11,100	250	60	11,410
Fall River	92,700	150	92,850	4,370	4,400	100	8,870
New Bedford [2]	99,920	140	100,060	18,180	1,590	90	19,860
Rehoboth	8,660	50	8,710	580	400	10	990
Seekonk	13,050	50	13,100	480	630	0	1,110
Somerset [3]	17,660	50	17,710	3,320	700	0	4,020
Swansea [3]	15,410	170	15,580	4,810	510	10	5,330
Westport [3]	13,850	1,830	15,680	1,740	680	80	2,500
TOTALS	314,170	4,750	318,920	48,600	10,800	1,070	60,470

NOTES:
[1] Acushnet is protected by the New Bedford Hurricane Barrier and therefore is not subject to surge flooding unless the barrier is overtopped.
[2] The New Bedford Hurricane Hurricane Barrier can be overtopped by category 4 hurricanes with forward speeds of 60 MPH or greater.
[3] Somerset, Swansea, and Westport have a single evacuation zone for all hurricane scenarios.

TABLE 4.3(c)
DUKES COUNTY
EVACUATING POPULATION
SEVERE HURRICANE SCENARIO

Community	Population of Town			Evacuating Population			
	Permanent	Seasonal	Total	Surge Areas	Non-Surge Areas	Mobile Homes	Total
Chilmark	820	4,620	5,440	1,140	210	0	1,350
Edgartown	3,760	32,060	35,820	11,420	1,160	20	12,600
Gay Head	310	1,140	1,450	280	60	10	350
Gosnold [1]	100	600	700	290	20	0	310
Oak Bluffs	2,940	24,430	27,370	6,270	1,020	10	7,300
Tisbury [1]	4,330	20,560	24,890	2,820	1,090	30	3,940
West Tisbury	1,610	5,610	7,220	950	310	10	1,270
TOTALS	13,870	89,020	102,890	23,170	3,870	80	27,120

NOTES:
[1] Gosnold and Tisbury have a single evacuation zone for all hurricane scenarios.

TABLE 4.3(d)
NANTUCKET COUNTY
EVACUATING POPULATION
SEVERE HURRICANE SCENARIO

Community	Population of Town			Evacuating Population			
	Permanent	Seasonal	Total	Surge Areas	Non-Surge Areas	Mobile Homes	Total
Nantucket [1]	8,500	36,290	44,790	10,730	1,660	0	12,390

NOTES:
[1] Nantucket has a single evacuation zone for all hurricane scenarios.

TABLE 4.3(e)
PLYMOUTH COUNTY
EVACUATING POPULATION
SEVERE HURRICANE SCENARIO

Community	Population of Town			Evacuating Population			
	Permanent	Seasonal	Total	Surge Areas	Non-Surge Areas	Mobile Homes	Total
Marion	4,500	1,130	5,630	5,080	0	0	5,080
Mattapoisett	5,850	1,650	7,500	5,510	70	20	5,600
Rochester	3,920	110	4,030	270	190	10	470
Wareham	19,230	18,800	38,030	22,850	520	2,190	25,560
TOTALS	33,500	21,690	55,190	33,710	780	2,220	36,710

4.4.2 Evacuee Response Time

Post hurricane evacuee response studies show a diversity in the rates at which evacuees leave their homes after being recommended to do so by authorities. This diversity can be primarily attributed to factors such as actions by local officials, severity of the threatening hurricane, residents' perception of the probability of the hurricane striking their location, and the evacuation difficulties for their location. The factor found to be the most consistent with each storm is the sharp increase in evacuation response following advice of local officials to evacuate. Fewer than 20 percent of eventual evacuees will leave before being told to leave. The increase in evacuation response following notification by local officials is consistent regardless of location, severity of the hurricane threat, or information previously disseminated to the threatened population.

One method to gain insight on how people may respond to local officials' recommendations in the future is to study what the same group of people did in past events. However, surveys of residents of Massachusetts conducted after Hurricane Gloria were for the most part inconclusive with regard to evacuation timing. This was primarily caused by interviewing too few evacuees and by conducting interviews two years after the event occurred. When asked, many people could not recall the precise times at which they left their homes. Similarly, surveys conducted after Hurricane Bob for the Hurricane Bob Preparedness Assessment for Coastal Areas of Southern New England and New York, May 1993 were only conducted with local officials. There were no response surveys involving the public. Thus the only estimates of evacuation timing were observations reported by local officials.

Even if actual response data were available for Hurricanes Gloria and Bob, evacuation timing cannot be generalized from a single event because the circumstances of each particular evacuation may vary considerably from storm to storm. This, however, does not present a problem in deriving planning assumptions about evacuation timing for a region. **Figure 4.1** provides a set of planning assumptions developed for Massachusetts based on results of an eight-state survey referenced in the report entitled Hurricane Evacuation Behavior in the Middle Atlantic and Northeast States (see Appendix B). In **Figure 4.1**, the curve on the left ("early") represents evacuee response when forecasts are early and residents are told to evacuate with plenty of warning. That scenario would probably be considered optimistic in most cases. For planning purposes, the study

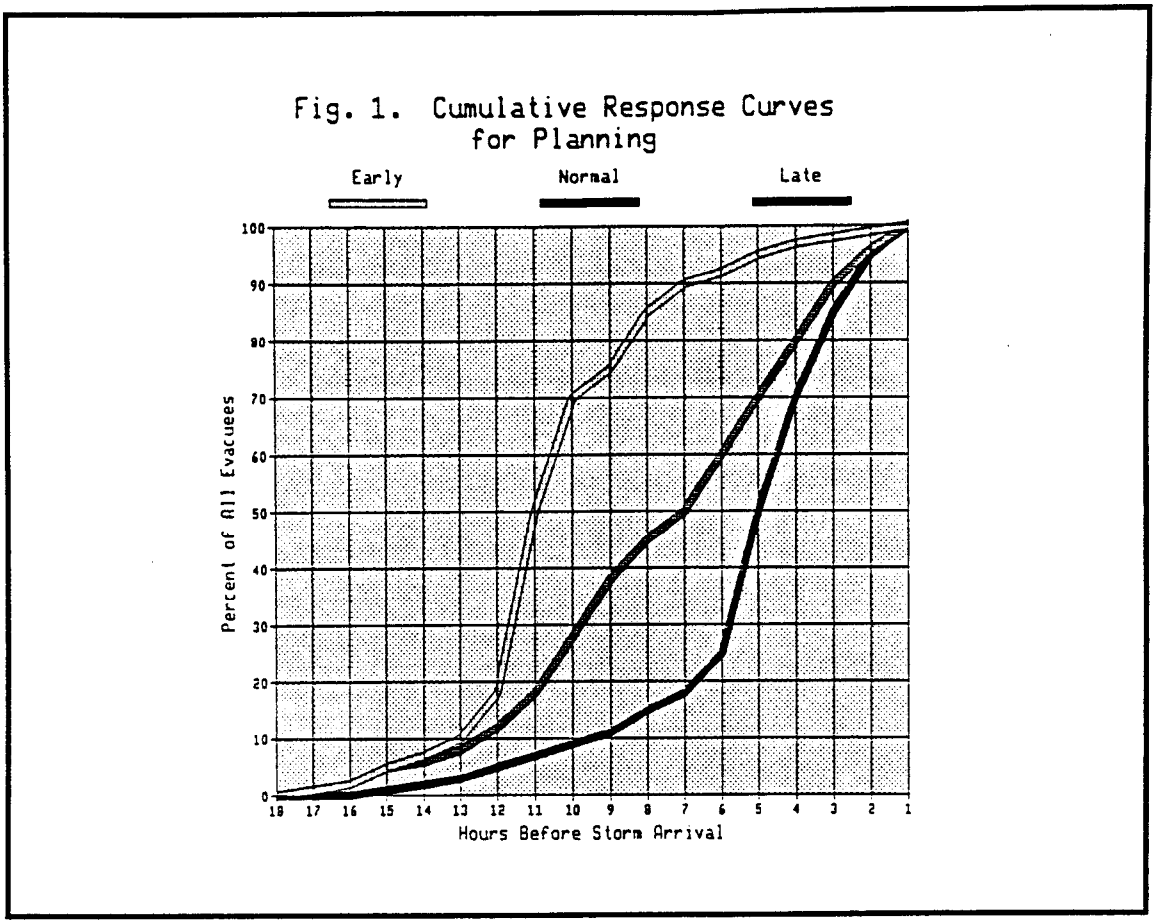

Figure 4.1 Cumulative Response Curves for Planning. Source: HMG, Inc.

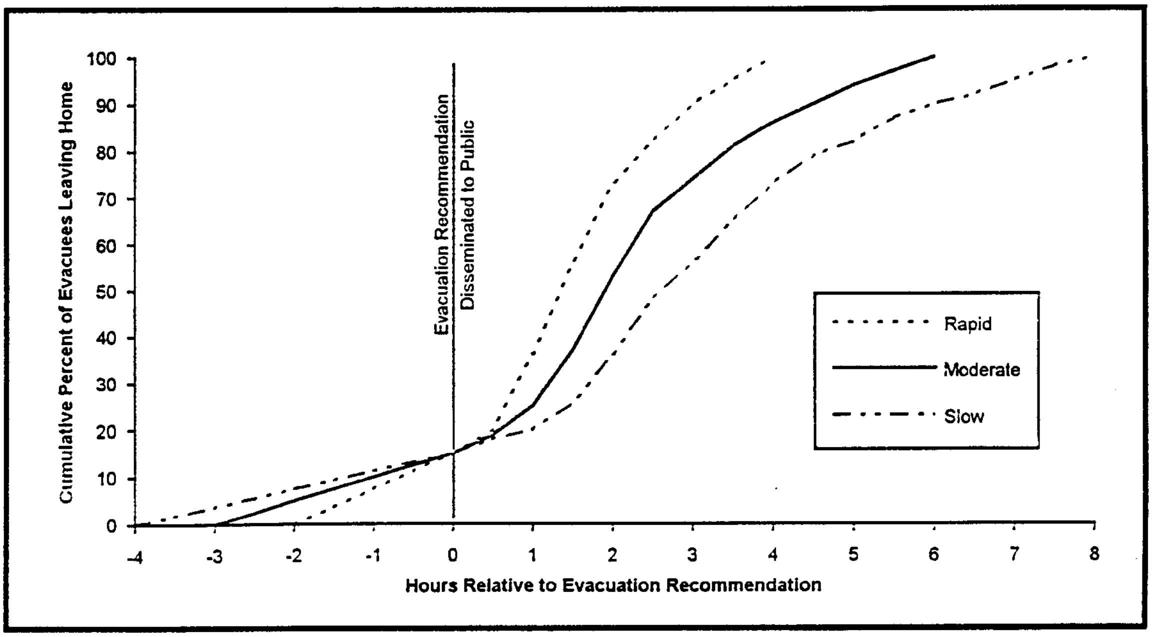

Figure 4.2 Evacuee Response Curves for Southern Massachusetts.

determined that the middle curve ("normal") is probably more typical. Warning is not quite as early in relation to the hurricane's assumed time of landfall. Finally, the curve on the right ("late") is likely to pertain when a storm accelerates, intensifies, or changes course unexpectedly. In this scenario, people are assumed to leave promptly provided that it is made clear that they must.

As mentioned before, one of the most influential factors in evacuation timing is the action taken by local authorities. Consequently, the timing at which the majority of eventual evacuees leave in relation to when an evacuation order or recommendation is disseminated to the public is a critical component to any planning response curve. The curves shown in **Figure 4.1** provide a starting point in developing evacuee response curves for the Southern Massachusetts Hurricane Evacuation Study, but provide little information on the precise times evacuation orders are assumed to occur in relation to when the majority of evacuees are assumed to leave. Therefore, evacuee response curves founded and used successfully in other State's hurricane evacuation studies, personal interviews of community officials after Hurricane Bob, and discussions with emergency management officials from the Commonwealth of Massachusetts provided a basis for modifying the **Figure 4.1** curves.

Figure 4.2 shows the three evacuee response curves that have been derived and used by this study for Massachusetts. The curves maintain the general shape of the "normal" curve in **Figure 4.1**, but the length of time evacuees are assumed to mobilize and leave is much shorter, and times at which evacuation recommendations are assumed to be issued in relation to landfall are specified. The terms "slow", "moderate", and "rapid" rates of evacuee response have been adopted for consistency with methodologies applied in other states' Hurricane Evacuation Studies. A "slow response" represents the situation in which residents are instructed to evacuate eight hours prior to the forecast arrival of gale force winds. The "moderate response" curve assumes a fairly rapid evacuee response in the last six hours before the forecast arrival of gale force winds and could be expected to apply to an evacuation prompted by a well publicized, steadily moving hurricane. Finally, the "rapid response" curve represents a "last minute" evacuation. This curve has the potential to occur if a storm dramatically increases speed, or suddenly changes course unexpectedly toward the State. Officials will have to hurriedly issue evacuation notices and make residents understand the urgency of a rapid evacuee response. For purposes of this study, the evacuee response curves in **Figure 4.2** are assumed to realistically represent the three levels of urgency that are likely to occur during hurricane evacuations in Massachusetts. The Transportation Analysis, presented in Chapter Six, discusses in detail how these curves were tested and related to roadway clearance time and total evacuation time.

4.4.3 Shelter Utilization Rates

Two factors which predominantly influence whether evacuees will seek public shelters as places of refuge are income and degree of hazard of the area being evacuated. Ten percent or less of the evacuees from beach and open coast areas normally use public shelters (an exception is in last-minute evacuations when there is insufficient time to travel to preferred destinations). Seldom will more than 20 percent of the surge-vulnerable residents further inland go to public shelters. Twenty percent of inland residents who are not threatened by hurricane flooding, but who still choose to evacuate, can be expected to seek public shelters if space is available.

The actions of local officials can greatly influence the sheltering rates within a community. The public would generally prefer to stay at inland homes of friends and relatives, or at hotels and motels, rather than shelters. However, if public shelters are opened early and advertised, public shelter utilization will be significantly higher than for areas where shelter locations and availability are not widely advertised.

Late night evacuations tend to maximize shelter utilization primarily because it occurs with a sense of urgency, leaving no time to make alternative arrangements, or little time to travel out of the region. Regardless of time of day, urgent evacuations in which evacuees are asked to respond rapidly roughly double shelter utilization compared to less urgent evacuations. Another factor which affects shelter utilization is that people living in retirement areas are more likely to use public shelters than other population types.

After consultation with American Red Cross and State emergency management officials, the shelter utilization rates shown in **Table 4.4** were assumed for this report. These percentages may vary depending on the evacuation circumstances of each location. Shelter utilization will increase if motorists intending to travel through a community are instead forced to stop, due to worsened road conditions, and seek safe designations at local shelters. Also, shelter usage may be higher if a significant number of tourists decide not to return home, but instead choose to ride out the storm at a nearby shelter.

TABLE 4.4
SHELTER UTILIZATION RATES[1]

EVACUATION ZONE "A"[2]	EVACUATION ZONE "B"[3]	MOBILE HOME RESIDENTS	NON-SURGE VULNERABLE POPULATION[4]
10 %	20 %	100 %	20 %

Notes:
[1] Shelter usage rates are applied to "weak storm" and "severe storm" evacuation scenarios (see page 3-2 for definitions).
[2] Evacuation zones closest to the coast as shown in the Evacuation Map Atlas.
[3] Evacuation zones farthest from the coast as shown in the Evacuation Map Atlas.
[4] Percentage of the community's evacuating "non-surge vulnerable population" assumed to use shelters.

4.4.4 Vehicle Usage Rates

Not all available vehicles are used in evacuations for fear of families being separated. Surveys taken after Gloria indicate that 65 to 75 percent of the available vehicles in a household were used during the evacuation. For the Transportation Analysis, it was assumed that 75 percent of the vehicles available to a household will be used. This figure was applied only to households assumed to be evacuating, not to all registered vehicles. As determined from the survey after Hurricane Gloria, none of the surveyed evacuees reported that they needed public transportation or assistance from a social service agency to evacuate. However, lists of names and addresses of all people needing special assistance are typically developed and maintained at the local level.

Chapter Five

SHELTER ANALYSIS

5.1 PURPOSE

The shelter analysis serves two primary purposes. The first is to estimate the number of evacuees who can be expected to utilize public shelters within each community. The second is to present inventories, capacities, and potential flood vulnerability of locally designated public shelters and American Red Cross (ARC) Mass Care Facilities.

5.2 REGIONAL AND LOCAL PUBLIC SHELTERS

It is the preference of state and local emergency management officials to open and operate an adequate number of public shelters to accommodate their own residents. To meet this goal, communities work with local ARC chapters to develop agreements for the use of public buildings and other facilities during emergencies. Before agreements are reached, buildings are evaluated using guidelines set forth by the American Red Cross in ARC 3031 (Mass Care Preparedness and Operations) and ARC Form 6564 (Mass Care Facility Survey). In addition, local officials identify other buildings as non-ARC public shelters.

5.3 SHELTER INVENTORIES

Tables 5.1 through **5.37** list the ARC Mass Care Facilities and local public shelters that have been identified for use during hurricane evacuations for each community. The tables include the facility's maximum sheltering capacity, a map key number corresponding to the facility's location shown in the Evacuation Map Atlas, and the susceptibility of buildings to surge and freshwater flooding. Names, capacities, and locations of locally designated shelters were furnished by local emergency management officials. The State ARC coordinator provided the building names and capacities of the Mass Care Facilities under agreement, as of November 1996, between communities and local ARC chapters.

It is important to note that a listing in this report does not imply that a facility will be used in a given hurricane evacuation. The choice of shelters is an operational decision made at the local level. Shelters will be opened by local officials and ARC personnel based on a variety of circumstances including severity of the hurricane threat, amount of advance warning time, services available at facilities, and availability of qualified people to manage the facilities. Also, shelter space will change as facilities are constructed or demolished, as ownership changes, and as agreements are reached or canceled with facility owners.

The susceptibility of the shelters listed in **Tables 5.1** through **5.37** to hurricane surge was assessed using surge limits delineated in the Inundation Map Atlas. Exposures of the shelters to 100-year and 500-year frequency flooding were assessed using the National Flood Insurance Plan rate maps published by FEMA. Shelters not located in or immediately adjacent to inundation areas, 500-year, and/or 100-year flood zones have been classified as not vulnerable to flooding. No attempt has been made to assess the vulnerability of locally designated shelters to hurricane winds.

As previously stated, some locally designated public shelters may not meet shelter selection guidelines established by the American Red Cross, and some communities may not have enough shelter capacity to meet estimated utilization. Evacuees who are not able to find shelter space within their own communities will probably travel farther distances to reach shelters in other communities, or find safe destinations elsewhere. The Transportation Analysis in Chapter Six discusses how clearance times may be affected by deficiencies in shelter capacity in general.

TABLE 5.1
TOWN OF ACUSHNET
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Ford Middle School	Yes	None	900
2	Middle Elementary School	No	None	600
3	Town Hall Annex	No	None	20
		TOTAL SHELTER CAPACITY		1,520

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.
[2] See Plate E-9 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood plain.

TABLE 5.2
TOWN OF BARNSTABLE
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Barnstable High School	Yes	None	1,200
2	Barnstable Middle School	No	Yes[5]	800
3	Osterville Elementary School	No	Yes[6]	400
		TOTAL SHELTER CAPACITY		2,400

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.
[2] See Plate E-19 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood plains.
[5] The facility is located in or near the 500-year floodplain of Dunns Pond as shown on Flood Insurance Rate Map Panel 5.
[6] The facility is located near the 500-year floodplain as shown on Flood Insurance Rate Map Panel 15; and near hurricane inundation zones A, B and C as shown on Plate I-19 of the companion Inundation Map Atlas.

TABLE 5.3
TOWN OF BOURNE
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Upper Cape Regional Vocational High School	Yes	None	500
2	Community Building	No	Yes[5]	150
3	Bourne High School (post landfall)	No	None	700
		TOTAL SHELTER CAPACITY		1,350

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.
[2] See Plate E-15 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood plain.
[5] The facility is located within or adjacent to the 500-year flood plain as shown on Flood Insurance Rate Map Panel 5; and within or adjacent to hurricane inundation zone A, B and C as shown on Plate I-19 of the companion Inundation Map Atlas.

TABLE 5.4
TOWN OF BREWSTER
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Brewster Elementary School	Yes	None	500
2	Our Lady of the Cape Roman Catholic Church	No	"	300
3	Ocean Edge Conference Center	No	"	150
4	Brewster VFW	No	"	100
5	Brewster Elementary School II (Eddy School)	Yes	"	450
		TOTAL SHELTER CAPACITY		1,500

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.
[2] See Plate E-22 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood plain.
[5] The location of this facility was not provided.

TABLE 5.5
TOWN OF CHATHAM
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Chatham Junior/Senior High School	Yes	None	600
2	Our Lady of Grace Roman Catholic Church	No	"	200
3	Holy Redeemer Roman Catholic Church	No	"	200
		TOTAL SHELTER CAPACITY		1,000

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.
[2] See Plate E-24 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood plain.

TABLE 5.6
TOWN OF CHILMARK
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Chilmark Community Center	No	None	60
2	Chilmark School	No	None	30
		TOTAL SHELTER CAPACITY		90

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.

[2] See Plate E-32 of the companion Evacuation Map Atlas for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood plains.

TABLE 5.7
TOWN OF DARTMOUTH
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Dartmouth High School	Yes	None	1,535
2	Dartmouth Senior Center	Yes	"	75
		TOTAL SHELTER CAPACITY		1,610

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.

[2] See Plate E-7 of the companion <u>Evacuation Map Atlas</u> for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood plains.

TABLE 5.8
TOWN OF DENNIS
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Nathaniel H. Wixon Middle School	Yes	None	800[5]
2	Dennis Senior Center	No	"	315[6]
3	Ezra Baker Elementary School	No	Yes[7]	1,015[8]
		TOTAL SHELTER CAPACITY		2,130

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.
[2] See Plate E-21 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.
[5] Per ARC. The Town of Dennis Building Inspector reports a shelter capacity of 500 persons in class rooms and 510 persons in the cafeteria for a total of 1010 persons.
[6] Per Town of Dennis. The ARC reports a shelter capacity of 500 persons.
[7] The facility lies within or adjacent to the 500-year flood plain as shown on Flood Insurance Rate Map Panel 8, and within or adjacent to hurricane inundation areas A, B and C as shown on Plate I-21 of the companion Inundation Map Atlas.
[8] Per Town of Dennis. The ARC reports a shelter capacity of 500 persons.

TABLE 5.9
TOWN OF EASTHAM
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Eastham Town Hall	No	None	100
2	Eastham Police Station	No	"	25
3	Nauset Regional High School (under construction)	Yes	"	1000[5]
		TOTAL SHELTER CAPACITY		125

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.

[2] See Plate E-26 of the companion Evacuation Map Atlas for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

[5] Capacity not included in total because the facility is under construction.

TABLE 5.10
TOWN OF EDGARTOWN
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Edgartown Elementary School	Yes	Yes [5]	300
2	Edgartown Boys and Girls Club	No	None	200
3	Edgartown Police Headquarters	No	Yes [6]	10
4	Edgartown Fire Station	No	Yes [6]	10
5	Federated Church	No	Yes [7]	30
6	St. Andrew's Episcopal Church Parish House	No	Yes [8]	30
7	Chappaquiddick Community Center	No	None	30
8	Edgartown United Methodist Church	No	Yes [9]	50
		TOTAL SHELTER CAPACITY		660

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.

[2] See Plate E-36 of the companion Evacuation Map Atlas for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood plains.

[5] The facility is located adjacent to hurricane inundation area C as shown on Plate I-36 of the companion Inundation Map Atlas.

[6] The facility is located within or adjacent to hurricane inundation area C as shown on Plate I-36 of the companion Inundation Map Atlas.

[7] The facility is located within or adjacent to the 100-year floodplain as shown on Flood Insurance Rate Map Panel 2; and within or adjacent to hurricane inundation areas A and B as shown on Plate I-36 of the companion Inundation Map Atlas.

[8] The facility is located within or adjacent to the 100-year floodplain as shown on Flood Insurance Rate Map Panel 2; and within or adjacent to hurricane inundation areas B and C as shown on Plate I-36 of the companion Inundation Map Atlas.

[9] The facility is located within or adjacent to hurricane inundation areas B and C as shown on Plate I-36 of the companion Inundation Map Atlas.

TABLE 5.11
TOWN OF FAIRHAVEN
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Wood School	Yes	Yes[5]	200
2	Hastings Middle School[6]	Yes	Yes[7]	200
		TOTAL SHELTER CAPACITY		400

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.

[2] See Plate E-10 of the companion Evacuation Map Atlas for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood plains.

[5] The facility is adjacent to the 500-year and 100-year flood plains as shown on Flood Insurance Rate Map Panel 3.

[6] The ARC has indicated that they will not staff this shelter prior to landfall of a hurricane. The facility may open as an ARC Mass Care Facility only in the post-landfall period, if long-term sheltering is required. The Fairhaven Emergency Management Director is encouraged to coordinate this issue with the ARC.

[7] The facility lies within hurricane inundation area D as shown on Plate I-10 of the companion Inundation Map Atlas. This means that it could be inundated by hurricane surge from certain category 3 and 4 hurricanes which landfall on critical storm tracks coincident with high astronomical tide.

TABLE 5.12
CITY OF FALL RIVER
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	B.M.C. Durfee High School	No	None	1,500
		TOTAL SHELTER CAPACITY		1,500

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.
[2] See Plate E-5 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood plains.

TABLE 5.13
TOWN OF FALMOUTH
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Falmouth High School	Yes	None	800
2	North Falmouth Elementary School	No	"	400
3	East Falmouth Elementary School	No	"	300
4	Lawrence Junior High School	No	"	400
		TOTAL SHELTER CAPACITY		1,900

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.

[2] See Plate E-16 of the companion Evacuation Map Atlas for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5.14
TOWN OF GAY HEAD
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Wampanoag Tribal Council of Gay Head	No	None	100
2	Gay Head Town Hall	No	None	50
		TOTAL SHELTER CAPACITY		150

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.
[2] See Plate E-31 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5.15
TOWN OF GOSNOLD
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Cuttyhunk Town Hall	No	None	50
		TOTAL SHELTER CAPACITY		50

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.
[2] See Plate E-30 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5.16
TOWN OF HARWICH
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Cape Cod Regional Technical High School	Yes	None	1,500
2	Harwich Intermediate School	No	"	500[5]
3	Harwich Elementary School	No	"	500
4	Harwich Town Hall	No	"	200
		TOTAL SHELTER CAPACITY		2,700

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.

[2] See Plate E-23 of the companion Evacuation Map Atlas for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

[5] Per Town of Harwich. ARC reports a shelter capacity of 400 persons.

TABLE 5.17
TOWN OF MARION
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Sippican School	Yes	Yes[5]	800
2	VFW Pavilion	No	None	225
		TOTAL SHELTER CAPACITY		1,025

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.
[2] See Plate E-12 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.
[5] The facility is located adjacent to the 500-year floodplain as shown on Flood Insurance Rate Map Panel 4; and adjacent to hurricane inundation areas B and C as shown on Plate I-12 of the companion Inundation Map Atlas.

TABLE 5.18
TOWN OF MASHPEE
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Mashpee Middle School	No	None	500
2	Mashpee High School	No	"	500
		TOTAL SHELTER CAPACITY		1,000

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.
[2] See Plate E-18 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5.19
TOWN OF MATTAPOISETT
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Old Rochester Regional High School	Yes	Yes[5]	1,500
		TOTAL SHELTER CAPACITY		1,500

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.

[2] See Plate E-11 of the companion Evacuation Map Atlas for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

[5] As shown on Plates I-11 and I-12 of the companion Inundation Map Atlas, Route 6 leading to and from the facility is likely to be inundated by hurricane surge. The Mattapoisett Emergency Management Director reports that the facility could be accessed from alternate routes in the event that access from Route 6 is cut off.

TABLE 5.20
TOWN OF NANTUCKET
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Nantucket High School	No	None	500

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.
[2] See Plate E-37 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5.21
CITY OF NEW BEDFORD
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Pulaski School	Yes	None	900
2	Greater New Bedford Regional Vocational Technical High School	Yes	"	2,700
3	Hayden-McFadden School	Yes	"	900
4	New Bedford High School	Yes	"	600
5	Carney Academy	Yes	"	900
			TOTAL SHELTER CAPACITY	6,000

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.

[2] See Plate E-8 of the companion Evacuation Map Atlas for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5.22
TOWN OF OAK BLUFFS
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Oak Bluffs Elementary School	Yes	Yes [5]	1,200
2	Martha's Vineyard Regional High School	No	None	2,000
3	Masonic Hall	No	None	50
4	Trinity Methodist Church Parish Hall	No	Yes [6]	30
5	Veterans of Foreign Wars	No	None	30
6	Holy Ghost Association	No	Yes [7]	50
7	Oak Bluffs Council on Aging	No	Yes [8]	30
		TOTAL SHELTER CAPACITY		3,390

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.

[2] See Plate E-35 of the companion Evacuation Map Atlas for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

[5] The facility is located within or adjacent to hurricane inundation areas B and C as shown on Plate I-35 of the companion Inundation Map Atlas.

[6] The facility is located within the 500-year floodplain and adjacent to the 100-year floodplain as shown on Flood Insurance Rate Map Panel 1; and within hurricane inundation area B as shown on Plate I-35 of the companion Inundation Map Atlas.

[7] The facility is located within or adjacent to hurricane inundation area C as shown on Plate I-35 of the companion Inundation Map Atlas.

[8] The facility is located within hurricane inundation area C as shown on Plate I-35 of the companion Inundation Map Atlas.

TABLE 5.23
TOWN OF ORLEANS
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Nauset Regional Middle School	Yes	None	1,000
2	Orleans Elementary School	No	"	300
		TOTAL SHELTER CAPACITY		1,300

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.
[2] See Plate E-25 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5.24
TOWN OF PROVINCETOWN
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Veterans Memorial Elementary School (Cafe.)	Yes	None	500[5]
2	Provincetown Town Hall	No	Yes[6]	130
3	Senior Citizen Center	No	None	120
4	VFW Hall	No	None	175
5	Community Center	No	Yes[7]	105
1	Veterans Memorial Elementary School (Gym)	No	None	200
6	Provincetown High School Gym	No	None	200
			TOTAL SHELTER CAPACITY	1,430

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.
[2] See Plate E-29 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.
[5] Per ARC. The Provincetown Emergency Management Director reports a shelter capacity of 450 persons.
[6] The facility is located adjacent to the 500-year flood plain as shown on Flood Insurance Rate Map Panel 3, and in or adjacent to hurricane inundation area C as shown on Plate I-29 of the companion Inundation Map Atlas.
[7] The facility is located adjacent to the 500-year flood plain as shown on Flood Insurance Rate Map Panel 3, and in or adjacent to hurricane inundation area C as shown on Plate I-29 of the companion Inundation Map Atlas.

TABLE 5.25
TOWN OF REHOBOTH
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Palmer River Elementary School	No	Yes[5]	200
2	Beckwith Middle School	No	Yes[5]	250
3	Dighton-Rehoboth Regional High School	No	None	400
		TOTAL SHELTER CAPACITY		850

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.
[2] See Plate E-2 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.
[5] The facility is located adjacent to the 500-year and 100-year flood plains as shown on Flood Insurance Rate Map Panel 3. In addition, Winthrop Street (Route 44) is shown to be inundated by the 500-year and 100-year flood zones in the vicinity of the facility.

TABLE 5.26
TOWN OF ROCHESTER
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Old Colony Regional Vocational Technical High School	Yes	None	200
		TOTAL SHELTER CAPACITY		200

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.

[2] See Plate E-13 of the companion Evacuation Map Atlas for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5.27
TOWN OF SANDWICH
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Sandwich Junior/Senior High School	Yes	None	1,000
2	Oak Ridge Elementary School	No	"	500
3	Forestdale Elementary School	No	"	500
		TOTAL SHELTER CAPACITY		2,000

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.
[2] See Plate E-17 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5.28
TOWN OF SEEKONK
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Seekonk Intermediate School	No	None	300
		TOTAL SHELTER CAPACITY		300

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.
[2] See Plate E-1 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5.29
TOWN OF SOMERSET
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Somerset High School	No	None	750
2	North Elementary School	No	"	750
3	Somerset Junior High School	No	"	750
		TOTAL SHELTER CAPACITY		2,250

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.

[2] See Plate E-4 of the companion Evacuation Map Atlas for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5.30
TOWN OF SWANSEA
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Case High School	No	None	300
2	Brown Elementary School	No	Yes[5]	75
3	Battleship Cove Emergency CB Club	No	Yes[6]	150
		TOTAL SHELTER CAPACITY		525

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.

[2] See Plate E-3 of the companion Evacuation Map Atlas for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

[5] The facility is adjacent to hurricane inundation areas B and C as shown on Plate I-3 of the companion Inundation Map Atlas.

[6] The access road to this facility is shown to be inundated by the 100-year flood plain as shown on Flood Insurance Rate Map Panel 5.

TABLE 5.31
TOWN OF TISBURY
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Tisbury Elementary School	Yes	None	250
2	Hebrew Center	No	None	130
3	St. Augustine's Roman Catholic Church	No	None	50
4	American Legion Hall	No	None	30
5	Grace Episcopal Church	No	None	30
6	Vineyard Playhouse	No	None	25
7	Council on Aging	No	None	50
8	Tisbury Fire Station	No	Yes [5]	20
9	Tisbury Inn	No	Yes [6]	100
10	Christ United Methodist Church	No	None	50
		TOTAL SHELTER CAPACITY		735

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.
[2] See Plate E-34 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.
[5] The facility is located within or adjacent to the 500-year and 100-year flood plains as shown on Flood Insurance Rate Map Panel 4; and within hurricane inundation area A as shown on Plate I-34 of the companion Inundation Map Atlas.
[6] The facility is located within or adjacent to the 500-year and 100-year floodplain as shown on Flood Insurance Rate Map Panel 4; and within or adjacent to hurricane inundation areas A, B and C as shown on Plate I-34 of the companion Inundation Map Atlas.

TABLE 5.32
TOWN OF TRURO
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Truro Central School	Yes	None	250
		TOTAL SHELTER CAPACITY		250

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.

[2] See Plate E-28 of the companion Evacuation Map Atlas for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5.33
TOWN OF WAREHAM
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Wareham High School	Yes	Yes[5]	890
2	Wareham Town Hall	Yes	Yes[5]	420
3	Multi-Service Center	No	Yes[5]	230
4	Wareham Middle School	No	Yes[5]	740
		TOTAL SHELTER CAPACITY		2,280

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.
[2] See Plate E-14 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.
[5] The facility lies within or adjacent to the 500-year flood plain as shown on Flood Insurance Rate Map Panel 8, and within hurricane inundation areas A, B and C as shown on Plate I-14 of the companion Inundation Map Atlas.

TABLE 5.34
TOWN OF WELLFLEET
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Wellfleet Elementary School	Yes	None	300
		TOTAL SHELTER CAPACITY		300

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.
[2] See Plate E-27 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5.35
TOWN OF WESTPORT
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Westport High School	No	None	750
		TOTAL SHELTER CAPACITY		750

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.

[2] See Plate E-6 of the companion Evacuation Map Atlas for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5.36
TOWN OF WEST TISBURY
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	West Tisbury Elementary School	No	None	800
2	Martha's Vineyard Agricultural Society	No	None	200
3	Up-Island Tisbury Council on Aging	No	Yes [5]	60
		TOTAL SHELTER CAPACITY		1,060

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.

[2] See Plate E-33 of the companion Evacuation Map Atlas for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

[5] The facility is located within or adjacent to hurricane inundation area C as shown on Plate I-33 of the companion Inundation Map Atlas.

TABLE 5.37
TOWN OF YARMOUTH
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Dennis Yarmouth Regional High School	Yes	None	850
2	Mattacheese Middle School	Yes	None	400
		TOTAL SHELTER CAPACITY		1,250

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters is an operational decision made by local emergency management officials.
[2] See Plate E-20 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

5.4 ESTIMATED SHELTER UTILIZATION VERSUS REPORTED CAPACITY

The results of the Vulnerability and Behavioral Analyses were used to estimate shelter utilization for two levels of evacuation: a "weak storm scenario" and a "severe storm scenario." **Tables 5.38** and **5.39** list the estimated shelter utilization for each community for the two scenarios. The tables also list each community's total reported public shelter capacity based on inventories of ARC Mass Care Facilities and locally designated public shelters. Comparisons between estimated shelter utilization and existing capacity reveal that 12 communities have less capacity than estimated utilization during a weak storm scenario, and that 15 communities have less capacity than estimated utilization for a severe storm scenario. These communities are encouraged to continue to work to identify additional public shelters to meet estimated sheltering needs.

Shelter utilization is one of the most difficult behavioral characteristics to predict. The estimated shelter utilization shown in **Tables 5.38** and **5.39** assume that there is an adequate warning period, that officials actively encourage residents to leave their homes, and that the public is aware of the locations and availability of public shelter facilities. The estimated shelter utilization is intended to be used as a guide, recognizing that more or less public shelter capacity may be needed depending on the evacuation circumstances and the aggressiveness of officials encouraging people to use public shelters. The population and behavioral assumptions used in estimating the number of evacuees and shelter utilization are as follows:

a. The percentage of the affected population (population living in evacuation zones) assumed to evacuate depends on the severity of the approaching hurricane. In a weak storm scenario, 80 percent of the population within Evacuation Zone A (see the Evacuation Map Atlas), and 40 percent within Evacuation Zone B, are assumed to evacuate. Under a severe storm scenario, 90 percent of the population living within either evacuation zone is assumed to evacuate.

b. The percentage of the unaffected population ("non-surge vulnerable population," excluding mobile home residents) that is assumed to evacuate is 2 percent during a weak storm scenario and 5 percent during a severe storm scenario. This population is not vulnerable to storm surge, but evacuates because of a perceived threat or because of wind hazards.

c. Ten percent of those evacuating from Evacuation Zone A (closest to the coast) are assumed to seek public shelter, and 20% of those evacuating from Evacuation Zone B (further from the coast) are assumed to seek public shelter. Twenty percent of the population evacuating from non-surge vulnerable areas (outside of the evacuation zones) is assumed to seek public shelter.

d. 100 percent of the mobile home residents are assumed to evacuate and seek public shelter.

e. Seasonal residents are assumed to evacuate and to seek public shelter at the same rates as the permanent population in their areas.

It is recognized that these assumptions may not may not fully represent the complex evacuation and sheltering situations of Martha's Vineyard, Nantucket, and Gosnold. However, lacking better information from the communities, the above assumptions were applied to those areas as well.

People evacuating the islands by ferry and returning to their vehicles on the mainland will likely impact traffic in the vicinity of Falmouth and Hyannis. This was observed during the evacuation prior to Hurricane Edouard over Labor Day Weekend in 1996, when traffic was backed up into Woods Hole. The additional traffic from Island evacuees was not directly accounted for in the Transportation Analysis. However, the sensitivity analysis did examine the potential impact of a 15% increase in the evacuating population. Those results, discussed in Section 6.8.2 and shown in Tables 5-3 and 5-4 of Appendix B, could be used to grossly assess the impact that the additional evacuees could have on traffic evacuating the Cape.

It is also recognized that the evacuation rates in **Table 4.1** may not fully represent the complex evacuation situations of Martha's Vineyard, Nantucket, and Gosnold. The Steamship Authority shuts down ferry service when weather conditions jeopardize operations.[1] All people desiring to evacuate the islands may not be able to do so. This was observed during the evacuation prior to Hurricane Edouard over Labor Day weekend. These factors are difficult to figure into an evacuation analysis. Therefore, the rates shown in **Table 4.1** were used to estimate the number of evacuees from Martha's Vineyard, Nantucket, and Gosnold as well.

[1]The Steamship Authority and the Massachusetts Emergency Management Agency are currently developing a contingency plan for natural disasters.

During the evacuation prior to Hurricane Bob in August 1991, the Bourne and Sagamore Bridges were closed approximately two hours before landfall due to high wind gusts. Emergency Management Officials in nearby communities opened additional shelter facilities to accommodate motorists stranded on highways at the time the bridges were closed. State Police report that they closed the bridges in response to recommendations from the Corps of Engineers Cape Cod Canal Field Office. The Canal Field Office recommends that the bridges be closed to high-profile vehicles such as tractor trailers, campers, and buses when <u>wind gusts</u> reach 70 knots (80 mph), and that the bridges be closed to all vehicles when <u>sustained winds</u> reach 70 knots. Since this study assumes that evacuation is completed prior to the arrival of gale force winds (34 knots, 39 mph), this potential additional sheltering requirement was not included in the estimated shelter utilization. However, based on evacuee response for Hurricane Bob, Emergency Management Officials in nearby communities should maintain contingency plans should the need arise to shelter motorists who cannot reach their intended destination because the bridges are closed.

TABLE 5.38(a)
BARNSTABLE COUNTY
ESTIMATED PUBLIC SHELTER UTILIZATION/CAPACITY
WEAK STORM EVACUATION SCENARIO

	Estimated Shelter Utilization by Population Type				
Community	Surge Vulnerable Residents	Non-surge Vulnerable Residents	Mobile Home Residents	Total Shelter Utilization	Reported Shelter Capacity [1]
Barnstable [4]	880	240	20	1,140	2,400
Bourne	1010	70	180	1,260	1,350
Brewster [4]	230	90	20	340	1,500
Chatham	540	70	0	610	1,000
Dennis [2,4]	1990	120	170	2,280	2,130
Eastham [2]	440	60	0	500	125
Falmouth [2]	2280	130	0	2,410	1,900
Harwich	800	80	10	890	2,700
Mashpee [2,4]	760	70	400	1,230	1,000
Orleans [4]	390	40	0	430	1,300
Provincetown [4]	380	30	20	430	1,430
Sandwich	340	70	30	440	2,000
Truro	100	30	10	140	250
Wellfleet [2,4]	600	30	540	1,170	300
Yarmouth [2]	1630	120	210	1,960	1,250
TOTALS	12,370	1,250	1,610	15,230	20,635

NOTES:
[1] Capacities of individual shelters within a community are listed in Tables 5.1 through 5.37.
[2] Reported shelter capacity is less than estimated shelter utilization.
[3] Estimated shelter utilization per community Emergency Management Director.
[4] Reported shelter capacity includes shelters which may be prone to flooding (see Tables 5.1 through 5.37)

TABLE 5.38(b)
BRISTOL COUNTY
ESTIMATED PUBLIC SHELTER UTILIZATION/CAPACITY
WEAK STORM EVACUATION SCENARIO

	Estimated Shelter Utilization by Population Type				
Community	Surge Vulnerable Residents	Non-surge Vulnerable Residents	Mobile Home Residents	Total Shelter Utilization	Reported Shelter Capacity [1]
Acushnet	70	30	600	700	1,520
Dartmouth	280	100	120	500	1,610
Fairhaven [2,4]	990	20	60	1,070	400
Fall River	390	350	100	840	1,500
New Bedford [3]	420	140	90	650	6,000
Rehoboth	50	30	10	90	850
Seekonk	40	50	0	90	300
Somerset	300	60	0	360	2,250
Swansea	420	40	10	470	525
Westport	160	60	80	300	750
TOTALS	3,120	880	1,070	5,070	15,705

NOTES:
[1] Capacities of individual shelters within a community are listed in Tables 5.1 through 5.37.
[2] Reported shelter capacity is less than estimated shelter utilization.
[3] Estimated shelter utilization per community Emergency Management Director.
[4] Reported shelter capacity includes shelters which may be prone to flooding (see Tables 5.1 through 5.37)

TABLE 5.38(c)
DUKES COUNTY
ESTIMATED PUBLIC SHELTER UTILIZATION/CAPACITY
WEAK STORM EVACUATION SCENARIO

	Estimated Shelter Utilization by Population Type				
Community	Surge Vulnerable Residents	Non-surge Vulnerable Residents	Mobile Home Residents	Total Shelter Utilization	Reported Shelter Capacity [1]
Chilmark [2]	100	20	0	120	90
Edgartown [2]	1,020	90	20	1,130	660
Gay Head	30	0	10	40	150
Gosnold [2]	140	0	0	140	50
Oak Bluffs	560	80	10	650	3,390
Tisbury	250	90	30	370	735
West Tisbury	80	30	10	120	1,060
TOTALS	2,180	310	80	2,570	6,135

NOTES:
[1] Capacities of individual shelters within a community are listed in Tables 5.1 through 5.37.
[2] Reported shelter capacity is less than estimated shelter utilization.
[3] Estimated shelter utilization per community Emergency Management Director.
[4] Reported shelter capacity includes shelters which may be prone to flooding (see Tables 5.1 through 5.37).

TABLE 5.38(d)
NANTUCKET COUNTY
ESTIMATED PUBLIC SHELTER UTILIZATION/CAPACITY
WEAK STORM EVACUATION SCENARIO

	Estimated Shelter Utilization by Population Type				
Community	Surge Vulnerable Residents	Non-surge Vulnerable Residents	Mobile Home Residents	Total Shelter Utilization	Reported Shelter Capacity [1]
Nantucket [2,3]	800	130	0	930	500

NOTES:

[1] Capacities of individual shelters within a community are listed in Tables 5.1 through 5.37.

[2] Reported shelter capacity is less than estimated shelter utilization.

[3] Estimated shelter utilization per community Emergency Management Director.

[4] Reported shelter capacity includes shelters which may be prone to flooding (see Tables 5.1 through 5.37)

TABLE 5.38(e)
PLYMOUTH COUNTY
ESTIMATED PUBLIC SHELTER UTILIZATION/CAPACITY
WEAK STORM EVACUATION SCENARIO

Community	Estimated Shelter Utilization by Population Type				
	Surge Vulnerable Residents	Non-surge Vulnerable Residents	Mobile Home Residents	Total Shelter Utilization	Reported Shelter Capacity [1]
Marion	450	0	0	450	1,025
Mattapoisett [4]	490	10	20	520	1,500
Rochester	20	20	10	50	200
Wareham [2,4]	2,030	40	2,190	4,260	2,280
TOTALS	2,990	70	2,220	5,280	5,005

NOTES:
[1] Capacities of individual shelters within a community are listed in Tables 5.1 through 5.37.
[2] Reported shelter capacity is less than estimated shelter utilization.
[3] Estimated shelter utilization per community Emergency Management Director.
[4] Reported shelter capacity includes shelters which may be prone to flooding (see Tables 5.1 through 5.37)

TABLE 5.39(a)
BARNSTABLE COUNTY
ESTIMATED PUBLIC SHELTER UTILIZATION/CAPACITY
SEVERE STORM EVACUATION SCENARIO

	Estimated Shelter Utilization by Population Type				
Community	Surge Vulnerable Residents	Non-surge Vulnerable Residents	Mobile Home Residents	Total Shelter Utilization	Reported Shelter Capacity [1]
Barnstable [4]	1,170	590	20	1,780	2,400
Bourne [2]	1,210	160	180	1,550	1,350
Brewster [4]	380	220	20	620	1,500
Chatham	680	160	0	840	1,000
Dennis [2,4]	2,830	310	170	3,310	2,130
Eastham [2]	670	150	0	820	125
Falmouth [2]	2,910	330	0	3,240	1,900
Harwich	1,310	200	10	1,520	2,700
Mashpee [2,4]	940	170	400	1,510	1,000
Orleans [4]	440	110	0	550	1,300
Provincetown [4]	730	70	20	820	1,430
Sandwich	520	180	30	730	2,000
Truro	120	80	10	210	250
Wellfleet [2,4]	940	80	540	1,560	300
Yarmouth [2]	2,710	290	210	3,210	1,250
TOTALS	17,560	3,100	1,610	22,270	20,635

NOTES:

[1] Capacities of individual shelters within a community are listed in Tables 5.1 through 5.37.

[2] Reported shelter capacity is less than estimated shelter utilization.

[3] Estimated shelter utilization per community Emergency Management Director.

[4] Reported shelter capacity includes shelters which may be prone to flooding (see Tables 5.1 through 5.37)

TABLE 5.39(b)
BRISTOL COUNTY
ESTIMATED PUBLIC SHELTER UTILIZATION/CAPACITY
SEVERE STORM EVACUATION SCENARIO

Community	Estimated Shelter Utilization by Population Type				
	Surge Vulnerable Residents	Non-surge Vulnerable Residents	Mobile Home Residents	Total Shelter Utilization	Reported Shelter Capacity [1]
Acushnet	160	80	600	840	1,520
Dartmouth	350	250	120	720	1,610
Fairhaven [2,4]	1,790	50	60	1,900	400
Fall River [2]	750	880	100	1,730	1,500
New Bedford [3]	4,550	400	90	5,040	6,000
Rehoboth	80	80	10	170	850
Seekonk	70	130	0	200	300
Somerset	330	140	0	470	2,250
Swansea [2]	480	100	10	590	525
Westport	170	140	80	390	750
TOTALS	8,730	2,250	1,070	12,050	15,705

NOTES:
[1] Capacities of individual shelters within a community are listed in Tables 5.1 through 5.37.
[2] Reported shelter capacity is less than estimated shelter utilization.
[3] Estimated shelter utilization per community Emergency Management Director.
[4] Reported shelter capacity includes shelters which may be prone to flooding (see Tables 5.1 through 5.37)

TABLE 5.39(c)
DUKES COUNTY
ESTIMATED PUBLIC SHELTER UTILIZATION/CAPACITY
SEVERE STORM EVACUATION SCENARIO

	Estimated Shelter Utilization by Population Type				
Community	Surge Vulnerable Residents	Non-surge Vulnerable Residents	Mobile Home Residents	Total Shelter Utilization	Reported Shelter Capacity [1]
Chilmark [2]	170	40	0	210	90
Edgartown [2]	1,690	230	20	1,940	660
Gay Head	30	10	10	50	150
Gosnold [2]	140	0	0	140	50
Oak Bluffs	980	200	10	1,190	3,390
Tisbury	280	220	30	530	735
West Tisbury	150	60	10	220	1,060
TOTALS	3,440	760	80	4,280	6,135

NOTES:
[1] Capacities of individual shelters within a community are listed in Tables 5.1 through 5.37.
[2] Reported shelter capacity is less than estimated shelter utilization.
[3] Estimated shelter utilization per community Emergency Management Director.
[4] Reported shelter capacity includes shelters which may be prone to flooding (see Tables 5.1 through 5.37)

TABLE 5.39(d)
NANTUCKET COUNTY
ESTIMATED PUBLIC SHELTER UTILIZATION/CAPACITY
SEVERE STORM EVACUATION SCENARIO

	Estimated Shelter Utilization by Population Type				
Community	Surge Vulnerable Residents	Non-surge Vulnerable Residents	Mobile Home Residents	Total Shelter Utilization	Reported Shelter Capacity [1]
Nantucket [2,3]	800	330	0	1,130	500

NOTES:
[1] Capacities of individual shelters within a community are listed in Tables 5.1 through 5.37.
[2] Reported shelter capacity is less than estimated shelter utilization.
[3] Estimated shelter utilization per community Emergency Management Director.
[4] Reported shelter capacity includes shelters which may be prone to flooding (see Tables 5.1 through 5.37)

TABLE 5.39(e)
PLYMOUTH COUNTY
ESTIMATED PUBLIC SHELTER UTILIZATION/CAPACITY
SEVERE STORM EVACUATION SCENARIO

	Estimated Shelter Utilization by Population Type				
Community	Surge Vulnerable Residents	Non-surge Vulnerable Residents	Mobile Home Residents	Total Shelter Utilization	Reported Shelter Capacity [1]
Marion	570	0	0	570	1,025
Mattapoisett [4]	630	10	20	660	1,500
Rochester	40	40	10	90	200
Wareham [2,4]	2,310	110	2,190	4,610	2,280
TOTALS	3,550	160	2,220	5,930	5,005

NOTES:
[1] Capacities of individual shelters within a community are listed in Tables 5.1 through 5.37.
[2] Reported shelter capacity is less than estimated shelter utilization.
[3] Estimated shelter utilization per community Emergency Management Director.
[4] Reported shelter capacity includes shelters which may be prone to flooding (see Tables 5.1 through 5.37).

5.5 PUBLIC SHELTER SELECTION GUIDELINES

In the future, some communities may choose to designate additional facilities as public shelters for use during hurricane evacuations. Shelter lists are also expected to change from year to year for various reasons. Whichever the case, it is important that shelters be carefully selected. In July 1992, the American Red Cross established guidelines for selecting shelters (ARC 4496). The guidelines, prepared by an interagency group, reflect the application of technical data compiled in Hurricane Evacuation Studies, other hazard information, and research findings related to wind loads and structural integrity. They are intended to supplement information contained in ARC 3031 and ARC Form 6564. These guidelines, which are reprinted on the following pages, are also appropriate for use by municipalities operating and selecting their own shelters. The American Red Cross does not consider the guidelines to be hard-and-fast rules for shelter selection. Rather, they are guidelines for evaluating and comparing prospective shelters.

Planning considerations for hurricane evacuation shelters involve a number of factors and require close coordination with local officials responsible for public safety. Technical information contained in Hurricane Evacuation Studies, storm surge and flood mapping, and other data can now be used to make informed decisions about the suitability of shelters.

In the experience of the American Red Cross, the majority of people evacuating because of a hurricane threat generally provide for themselves or stay with friends and relatives. However, for those who do seek public shelter, **safety from the hazards associated with hurricanes must be assured.** These hazards include-

- Surge inundation.
- Rainfall flooding.
- High winds.
- Hazardous materials.

Recommended guidelines follow for each of these hurricane-associated hazards.

Surge Inundation Areas

In general, hurricane evacuation shelters should not be located in areas vulnerable to hurricane surge inundation. The National Weather Service has developed mathematical models, such as Sea, Lake, and Overland Surges from Hurricanes (SLOSH) and Special Program to List Amplitudes of Surges from Hurricanes (SPLASH), that are critical in determining the potential level of surge inundation in a given area.

- Carefully review inundation maps in order to locate all hurricane evacuation shelters outside Category 4 storm surge inundation zones.
- Avoid buildings subject to isolation by surge inundation in favor of equally suitable buildings not subject to isolation. Confirm that ground elevations for all potential shelter facilities and access routes obtained from topographic maps are accurate.
- Do not locate hurricane evacuation shelters on barrier islands.

Rainfall Flooding

Rainfall flooding must be considered in the hurricane evacuation shelter selection process. Riverine inundation areas shown on Flood Insurance Rate Maps (FIRMSs), as prepared by the National Flood Insurance Program, should be reviewed. FIRMs should also be reviewed in locating shelters in inland counties.

- Locate hurricane evacuation shelters outside the 100-year floodplain.
- Avoid selecting hurricane evacuation shelters located within the 500-year floodplain.
- Do not locate hurricane evacuation shelters in areas likely to be isolated due to riverine inundation of roadways.
- Make sure a hurricane evacuation shelter's first floor elevation is on an equal or higher elevation than that of the base flood elevation level for the FIRM area.
- Consider the proximity of shelters to any dams and reservoirs to assess flow upon failure of containment following hurricane-related flooding.

Wind Hazards

Consideration of any facility for use as a hurricane evacuation shelter must take into account wind hazards. Both design and construction problems may preclude a facility from being used as a shelter. Local building codes are frequently inadequate for higher wind speeds.

Structural Considerations

- If possible, select buildings that a structural engineer has certified as being capable of withstanding wind loads according to ASCE (American Society of Engineers) 7-88 or ANSI (American National Standards Institute) A58 (1982) structural design criteria. Buildings must be in compliance with all local building and fire codes.
- Failing a certification (see above), request a structural engineer to rank the proposed hurricane evacuation shelters based on his or her knowledge and the criteria contained in these guidelines.
- Avoid uncertified buildings of the following types:
  - Buildings with long or open roof spans
  - Un-reinforced masonry buildings
  - Pre-engineered (steel pre-fabricated) buildings built before the mid 1980s
  - Buildings that will be exposed to the full force of hurricane winds
  - Buildings with flat or lightweight roofs
- Give preference to the following:
  - Buildings with steep-pitched, hipped roofs; or with heavy concrete roofs

- Buildings more than one story high (if lower stories are used for shelter)
- Buildings in sheltered areas
- Buildings whose access routes are not tree-lined

Interior Building Safety Criteria During Hurricane Conditions

Based on storm data (e.g., arrival of gale-force winds), determine a notification procedure with local emergency managers regarding when to move the shelter population to pre-determined safer areas within the facility. Consider the following guidelines:

- Do not use rooms attached to, or immediately adjacent to, un-reinforced masonry walls or buildings.
- Do not use gymnasiums, auditoriums, or other large open areas with long roof spans during hurricane conditions.
- Avoid areas near glass, unless the glass surface is protected by an adequate shutter. Assume that windows and roof will be damaged and plan accordingly.
- Use interior corridors or rooms.
- In multi-story buildings, use only the lower floors and avoid corner rooms.
- Avoid any wall section that has portable or modular classrooms in close proximity, if these are used in your community.
- Avoid basements if there is any chance of flooding.

Hazardous Materials

The possible impact from a spill or release of hazardous materials should be taken into account when considering any potential hurricane evacuation shelter.

All facilities manufacturing, using, or storing hazardous materials (in reportable quantities) are required to submit Material Safety Data Sheets (emergency and hazardous chemical inventory forms) to the Local Emergency Planning Committee (LEPC) and the local fire department. These sources can assist you in determining the suitability of a potential hurricane evacuation shelter or determining precautionary zones (safe distances) for facilities near potential shelters that manufacture, use, or store hazardous materials.

- Facilities that store certain types or quantities of hazardous materials may be inappropriate for use as hurricane evacuation shelters.
- Hurricane evacuation shelters should not be located within the ten-mile emergency planning zone (EPZ) of a nuclear power plant.
- Service delivery units must work with local emergency management officials to determine if hazardous materials present a concern for potential hurricane evacuation shelters.

Hurricane Evacuation Shelter Selection Process

General procedures for investigating the suitability of a building or facility for use as a hurricane evacuation shelter are as follows:

- Identify potential sites. Evacuation and transportation route models must be considered.
- Complete a risk assessment on each potential site. Gather all pertinent data from SLOSH and/or SPLASH (storm surge), FIRM (flood hazard), facility base elevation, hazardous materials information, and previous studies concerning each building's suitability.
- Inspect the facility and complete a *Red Cross Facility Survey Form and a Self-Inspection Work Sheet/Off-Premises Liability Checklist*, in accordance with ARC 3031. Note all potential liabilities and the type of construction. Consider the facility as a whole—one weak section may seriously jeopardize the integrity of the building.
- Have the building certified as being capable of withstanding the wind loads according to ASCE 7-88 or ANSI A58 (1982) structural design criteria. In the absence of certification, have a structural engineer review the facility and rate its suitability to the best of his or her ability.
- Ensure that an exhaustive search for shelter space has been completed. Work with local emergency management officials and others to identify additional potential sites.
- Review, on a regular basis, all approved hurricane evacuation shelters. Facility improvements, additions, or deterioration may change the suitability of a selected facility as a hurricane evacuation shelter. Facility enhancements may also enable previously rejected facilities to be used as hurricane evacuation shelters.
- If possible, work with officials, facility managers, and school districts on mitigation opportunities.

Continue to advocate that the building program for new public buildings, such as schools, should include provisions to make them more resilient to possible wind damage. It may also be possible to suggest a minor modification of a municipal, community, or school building in the planning stages to make for a more useful hurricane evacuation shelter site, such as the addition of hurricane shutters.

Least-Risk Decision Making

Safety is the primary consideration for the American Red Cross in providing hurricane evacuation shelters. When anticipated demands for hurricane evacuation shelter spaces exceed suitable capacity as defined by the preceding criteria, there may be a need to utilize marginal facilities. It is therefore critical that these decisions be made carefully and in consultation with local emergency management and public safety officials. Guidance should be obtained from Disaster Services at national headquarters, in consultation with the Risk Management Division.

This process should include the following considerations:

- No hurricane evacuation shelter should be located in an evacuation zone for obvious safety reasons. All hurricane evacuation shelters should be located outside of Category 4 storm surge inundation zones. **Certain exceptions may be necessary, but only if there is a high degree of confidence that the level of wind, rain, and surge activities will not surpass established shelter safety margins.**
- When a potential hurricane evacuation shelter is located in a flood zone, it is important to consider its viability. By comparing elevations of sites with FIRMs, one can determine if the shelter and a major means of egress are in any danger of flooding. Zone AH (within the 100-year flood plain and puddling of 1-3 feet expected) necessitates a closer look at the use of a particular facility as a sheltering location. Zones B, C, and D may allow some flexibility. **It is essential that elevations be carefully checked to avoid unnecessary problems.**
- In the absence of certification by a structural engineer, any building selected for use as a hurricane evacuation shelter must be in compliance with all local building and fire codes. Certain exceptions may be necessary, but only after evaluation of each facility, using the aforementioned building safety criteria.
- The Red Cross uses the planning guideline of 40 square feet of space per shelter resident. During hurricane conditions, on a short-term basis, shelter space requirements may be reduced. Ideally, this requirement should be determined using no less than 20 square feet per person. Adequate space must be set aside for registration, health services, and safety and fire considerations. Disaster Health Services areas should still be planned using a 40 square feet per person calculation. On a long-term recovery basis, shelter space requirements should follow guidelines established in ARC 2021, *Mass Care: Preparedness and Operations.*

Chapter Six

TRANSPORTATION ANALYSIS

6.1 PURPOSE

The purpose of the Transportation Analysis is to estimate roadway clearance times for coastal communities in southern Massachusetts under a variety of hurricane evacuation scenarios. Clearance time is defined as the amount of time required for vehicles to clear the roadways after a regional or state level hurricane evacuation recommendation has been disseminated to the public. During an evacuation, a large number of vehicles have to travel on the road system in a relatively short period of time. A number of different vehicle trips are possible, varying by trip origination, time of departure, and trip destination. The number of vehicle trips becomes particularly significant for an area such as the Massachusetts coast because its land areas are highly urbanized with many residents living near the immediate shore. The number of evacuating vehicles varies depending on the intensity of the hurricane, actions taken by local authorities, and certain behavioral response characteristics of the area's population. Motorists evacuating their homes and intermixing with traffic from people leaving work or traveling for other trip purposes can lead to significant traffic congestion and backups, ultimately delaying the evacuation.

This analysis establishes the roadway clearance time portions of evacuation times. Clearance time is one component of the total time required to complete a regional hurricane evacuation. The amount of time necessary for public officials to notify people to evacuate must be added to the estimated roadway clearance time to determine total evacuation time. Chapter Seven discusses recommended roadway clearance times to use in estimating total evacuation times for decision-making purposes.

A numerical model of the roadway system in southern Massachusetts was developed to assist in estimating roadway clearance times for the study area. General information and data related to the Transportation Analysis are presented in summary form in this chapter. A more detailed description of the Transportation Analysis is provided in Appendix D, Transportation Analysis Support Documentation.

6.2 METHODOLOGY

Clearance time calculations are complicated by the vast number of possible destinations and routes available to evacuees in highly populated areas. Clearance time calculations are further complicated by the affects of significant and varying amounts of background traffic that will be present on roadways as an evacuation progresses. Background traffic refers to vehicle trips by people who leave work early and return home, people who travel through the region, and trips made by people preparing for the arrival of hurricane conditions or engaged in normal activities.

The study considered several approaches to estimate roadway clearance times for the southern Massachusetts study area. The first approach considered was the one used by the Corps of Engineers and FEMA to complete Hurricane Evacuation Studies in the Gulf and southern Atlantic coast states. This approach assigns destinations and evacuation routes for the evacuating population by matching probable evacuee destinations (determined by a behavioral analysis) with the land uses known for the region. A mathematical model of the study area's roadway system is then used to calculate roadway clearance times based on the trip distributions assumed for the evacuation. The time required for all evacuees to reach their predetermined destination is considered the clearance time.

As reported in a post hurricane assessment of Hurricane Hugo in 1989, the transportation analyses conducted for the North Carolina and South Carolina Hurricane Evacuation Studies were found to be very accurate in that the roadway clearance times experienced during evacuations were very close to predicted times. These results give evidence that this approach is accurate for study areas with moderate roadway systems and where land use information is suitable to identify evacuation routes and predict the destinations of evacuees. The following paragraphs explain some differences in the southern Massachusetts study area in comparison to other coastal areas, and gives the reasons why the Corps of Engineers employed an alternative transportation modeling approach for southern Massachusetts.

One concern in using the land use modeling approach for southern Massachusetts was the appropriateness of designating evacuee destinations and evacuation routes. In the Gulf and southern Atlantic coast states, inundation areas extend several miles inland.

There is a limited road network available to those evacuating inundation areas, which makes it easier to determine the routes evacuees will take to stay in shelters. Also, land uses are separated by geographic area. That is, hotels and motels are located in separate and distinct areas away from other evacuation destinations such as the homes of friends and relatives.

In contrast, inundation areas in most of the southern Massachusetts study communities are confined to narrow, densely populated bands along the coast and tidal rivers. The complex system of interconnecting highways, undivided state routes, and numerous local streets in southern Massachusetts offer evacuees, and others on the roadways, many possible travel routes to reach their destinations. Southern Massachusetts is generally characterized by diverse land uses in small geographic areas. Hotels and motels are not located in an area separate from other land uses, but are interspersed with other evacuation destinations. In addition, each community tends to open public shelters as required to accommodate demand. Therefore, it is not practical to use land use information to derive specific assumptions about evacuee destinations and evacuation routes.

The second concern in applying the modeling approach used in other studies for southern Massachusetts was the proportion of people evacuating from vulnerable areas in comparison to the number of background vehicles expected on roadways during evacuations. Although surge areas are densely populated, the relatively small land areas that they encompass include only a small portion of the region's total population. When viewing the region's roadways as an entire transportation system, most of the traffic on roadways during initial and mid stages of an evacuation is likely to be from people leaving work early and from vehicles passing through the region. During an evacuation, evacuating vehicles are forced to compete for roadways with a large amount of background traffic. This can cause increased congestion, potentially delaying the overall evacuation. Because background traffic will travel in both directions on nearly all roadways during evacuations, it was determined that the transportation methodology for southern Massachusetts should not focus on assigning evacuation routes as is typically done in other study areas. Instead, the methodology should emphasize the influence background traffic can have on the overall evacuation.

To address the behavioral and transportation issues typical of the southern Massachusetts study area, an alternative modeling strategy was used. A mathematical model of the road system was developed and calibrated to simulate the traffic flows of a normal weekday in August. Empirical traffic engineering studies and traffic count data available from the Massachusetts Highway Department and the Cape Cod Commission were used to calibrate the model. The transportation modeling methodology assumes that the preferences of evacuees to travel on given routes are related to the traffic patterns of a normal summer day, except where it is clear that evacuees will travel directly to public shelters. Therefore, specific destinations and evacuation routes are not assigned to evacuees traveling to hotels, motels and to the homes of friends and relatives.

Large business districts and confined hurricane surge areas in most coastal communities in Massachusetts will give rise to evacuations involving mostly traffic generated by people leaving work rather than people evacuating surge areas. Analysis of traffic data collected on the days of Hurricanes Gloria and Bob support this assumption. Accordingly, the modeling strategy used in southern Massachusetts focuses on estimating roadway clearance times which qualitatively measure how competition by evacuating traffic may affect, and possibly delay, the movement of all traffic during an evacuation.

6.3 ROAD NETWORKS

The study area for the Transportation Analysis includes all of Barnstable County and the coastal communities of Plymouth and Bristol Counties, as shown in Figure 6.1. The transportation analysis did not include Dukes and Nantucket Counties. It is the intention of the communities in those counties that those desiring to leave the islands would do so in advance of an evacuation decision. Those choosing to remain on the islands would be accommodated at designated shelters.

The road system under examination includes State highways and major roadways in the Buzzards Bay area and on Cape Cod. The vastness of the southern Massachusetts study area required that the roadway system be divided into two approximately equal sized networks and analyzed individually. The two roadway networks were defined as the "Buzzards Bay" network and the "Cape Cod" network. The towns included in the Buzzards Bay network are: Fall River, Westport, Dartmouth, New Bedford, Acushnet,

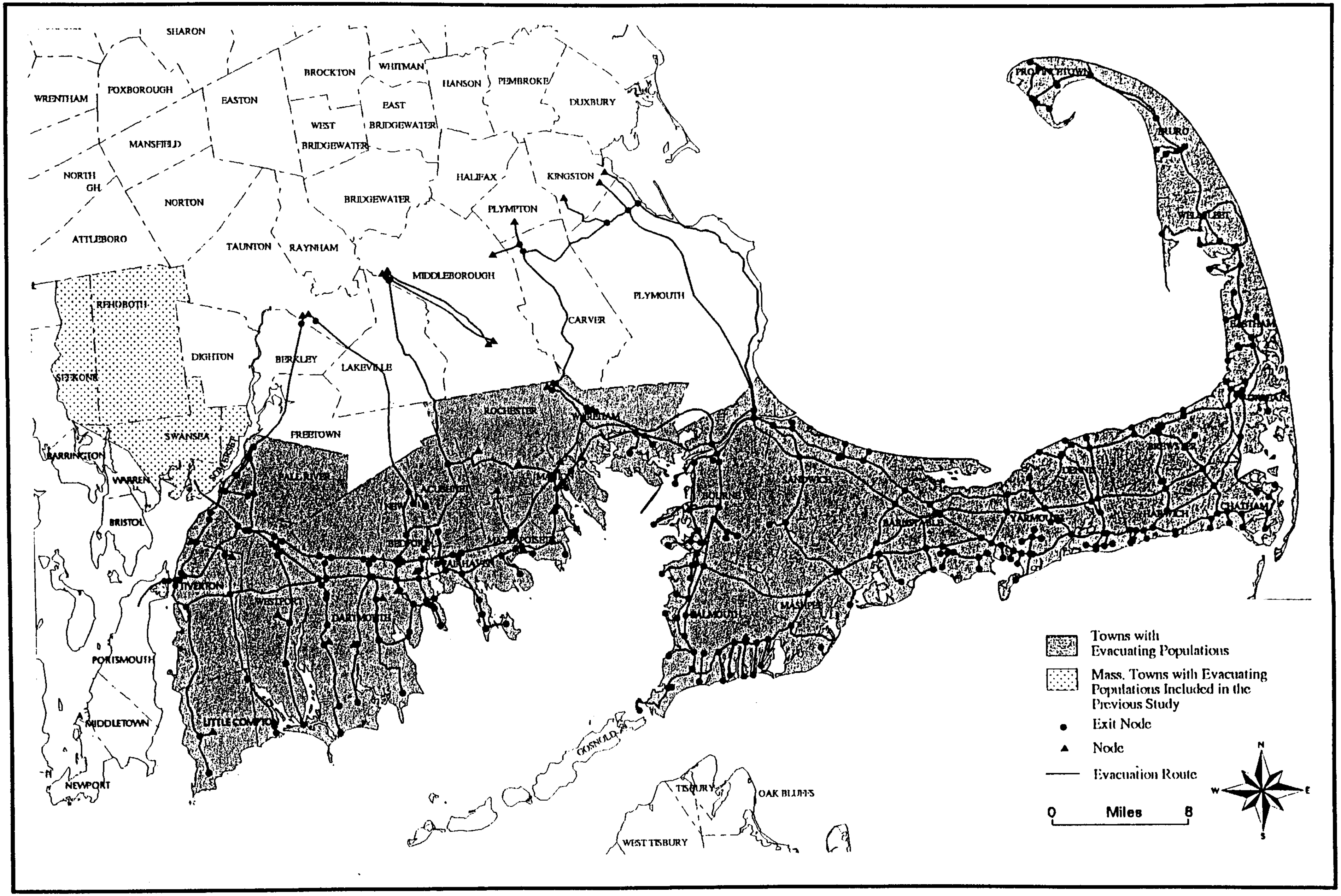

Figure 6.1 Transportation Network.

Fairhaven, Mattapoisett, Marion, and Rochester. The towns of Little Compton and Tiverton, Rhode Island were included in the Buzzards Bay network because of the interdependence and inseparability of the eastern Rhode Island and Southern Massachusetts roadway systems. The towns included in the Cape Cod network are: Wareham, Bourne, Falmouth, Mashpee, Sandwich, Barnstable, Yarmouth, Dennis, Harwich, Brewster, Chatham, Orleans, Eastham, Wellfleet, Truro, and Provincetown.

The Bristol County, Massachusetts communities of Seekonk, Rehoboth, Swansea, and Somerset were included in the East Bay/Massachusetts network of the Rhode Island Hurricane Evacuation Study. These communities were not included in the Buzzards Bay network of this study for the following reasons:

- The Taunton River is assumed to be a representative western endpoint for evacuating traffic from the Buzzards Bay network because it is assumed that most evacuating traffic will choose routes that avoid going through a major urban area, such as Fall River, for less congested routes that will get them inland faster.

- The percentage increase in summer traffic for Bristol County routes east of the Taunton River is generally greater than the percentage increase of summer traffic for communities west of the Taunton River. This observation provides justification for the assertion that the Buzzards Bay background traffic behaves in a transitional manner between that of Rhode Island, which has a relatively small percentage increase in summer versus average daily traffic, and Cape Cod, which has the greatest percentage increase in summer versus average daily traffic.

Clearance times for Seekonk, Rehoboth, Swansea, and Somerset were calculated in the Rhode Island Hurricane Evacuation Study, and were compared to clearance times calculated for the Buzzards Bay network in this study. The results are discussed in Section 6.7.2.

The transportation model used for this analysis was NETVAC2, a special purpose evacuation computer program used to create a mathematical model of study area's roadway system. In NETVAC2, links are used to represent roadways, and nodes are used to represent the intersections that connect two or more roadways. The physical characteristics for links and nodes are inputs to the model necessary to compute roadway capacity constraints and legal turning movements at intersections. Detailed link and node configurations of the road network are shown in Figures 2-1 through 2-10 in Appendix D.

The Massachusetts Highway Department and the Cape Cod Commission provided information for the roadway and intersection data. Roadway information input to the model included the number of travel lanes and auxiliary lanes, lane widths, and intersection approach widths. The total length of each road segment was measured from a scaled map of the roadway network. Functional classification of routes and land use information were also included. Field surveys were conducted at several locations to verify that the modeling strategy and data input in the models were consistent with physical conditions. More information pertaining to specific information input to the model is given in Appendix D.

This study assumes that evacuation is completed prior to the arrival of sustained gale force winds (34 knots, 39 mph), and that all highway bridges will be fully operational during evacuations. State Police report that they close the Bourne and Sagamore bridges in response to recommendations from the Corps of Engineers Cape Cod Canal Field Office. The Canal Field Office recommends that the bridges be closed to high-profile vehicles such as tractor trailers, campers, and buses when <u>wind gusts</u> reach 70 knots (80 mph), and that the bridges be closed to all vehicles when <u>sustained winds</u> reach 70 knots.

6.4 MODEL CALIBRATION

Before evacuation simulations were run, each network was calibrated to represent its study area. Calibration is performed for two reasons. First, it establishes the route preferences that will be used by all vehicles during an evacuation simulation (route preferences control the numbers of vehicles assigned to travel on each road). Second, it determines how many vehicles must be loaded at a given loading rate to achieve traffic patterns typical of a normal August weekday. Before an evacuation is initiated, the modeling methodology assumes traffic patterns of a normal August weekday occur. Therefore, NETVAC2 was programmed to simulate normal traffic patterns at the start of all model runs. Only after a hurricane threat becomes imminent, and people begin responding to warnings, are changes in normal traffic anticipated.

The Massachusetts Highway Department and the Cape Cod Commission tabulate the average daily traffic (ADT) data for all state maintained roadway segments where significant changes in total traffic volume occur. The average daily traffic represents the expected number of vehicles to pass by a given location during any normal day. The distribution of average daily traffic over a 24-hour period varies with each hour and day of the week. In general, the percentage of average daily traffic is usually many times greater during peak traffic periods compared with times of off-peak traffic. Figure 6.2(a) shows the 24-hour traffic distribution for the Buzzards Bay network, and Figure 6.2(b) shows the 24-hour traffic distribution for the Cape Cod network.

In Figures 6.2(a) and (b), the dotted lines delineate approximate levels of average daily traffic corresponding to off-peak, mid-peak, and peak traffic conditions. For the most part, off-peak traffic refers to light traffic volumes that typically occur late at night or early in the morning. Mid-peak traffic refers to moderate traffic conditions experienced in the late morning or early afternoon on weekdays, or on weekend days. Peak traffic represents the volume of traffic that is typical during weekday afternoon rush hour. Although the distribution of average daily traffic in Figures 6.2(a) and (b) may not reflect all of the local traffic patterns for each road in the study area, it does represent how most vehicle trips in the Buzzards Bay and Cape Cod road networks are distributed over a normal August weekday. Therefore, Figures 6.2(a) and (b) were used as a basis by which all roadways within the two networks were calibrated.

For the final calibration test, focus was placed on 26 key roadway links to evaluate overall results (see Appendix D). The actual unidirectional average daily traffic at all exterior nodes in the networks was entered as vehicles and programmed to flow throughout each network. As simulations progressed, printouts every hour of simulation time reported the cumulative link (roadway) departures and link speeds, as well as any spill backs and queues found at nodes (intersections). Calibration was accomplished using an iterative process of running NETVAC2, comparing modeled two-way average daily traffic to actual 2-way average daily traffic for the 26 links, then adjusting link preference factors and adding traffic onto the network where appropriate before rerunning the model.

During this process, a loading distribution that approximated average actual conditions for the index locations was achieved. Major corridors, such as I-195 and Route 6, were also reviewed in detail to ensure that the 26 focus locations were not isolated

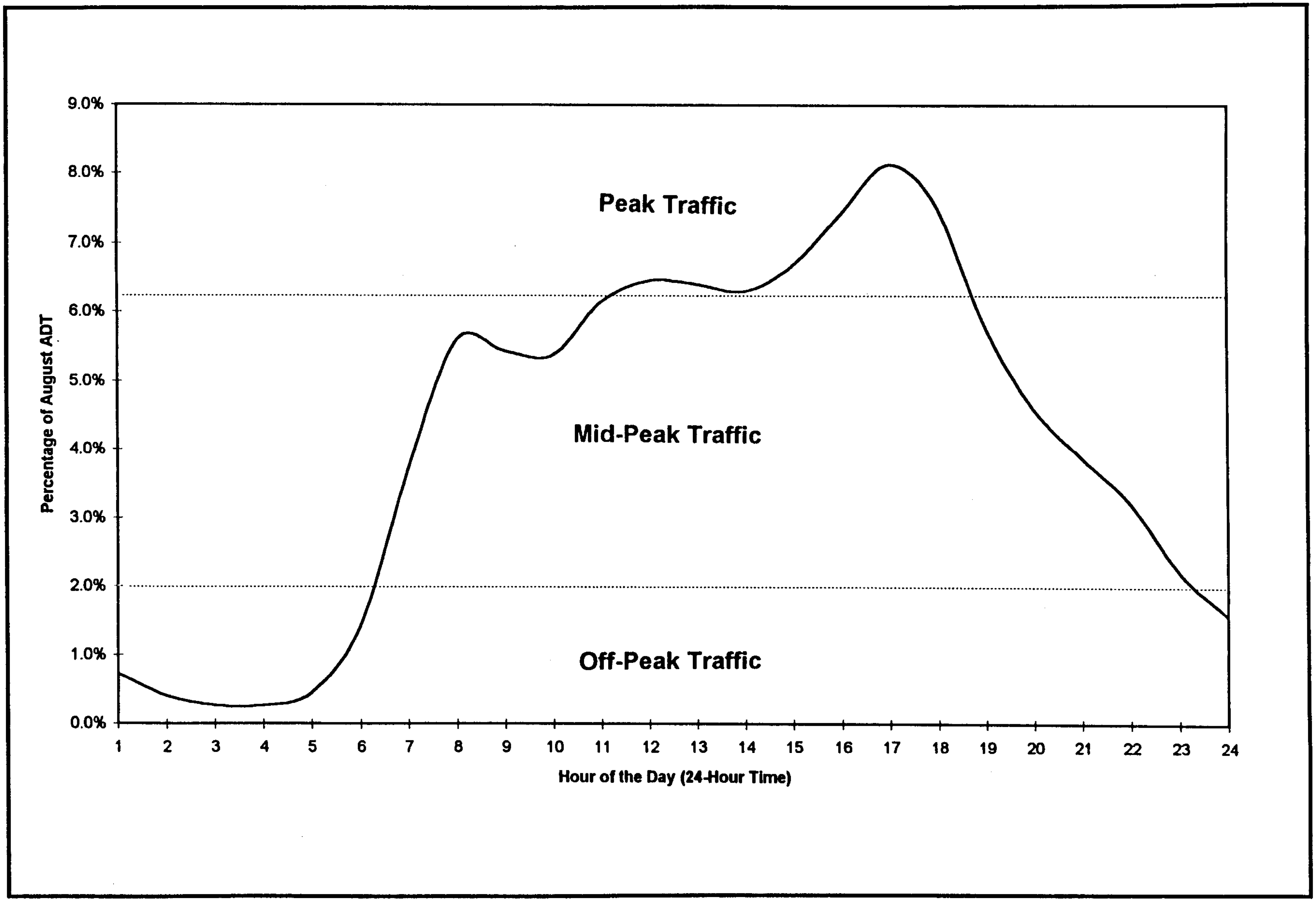

Figure 6.2a Weighted Average of Hourly ADT Along Major Routes in Southern Massachusetts - Buzzards Bay Road Network.

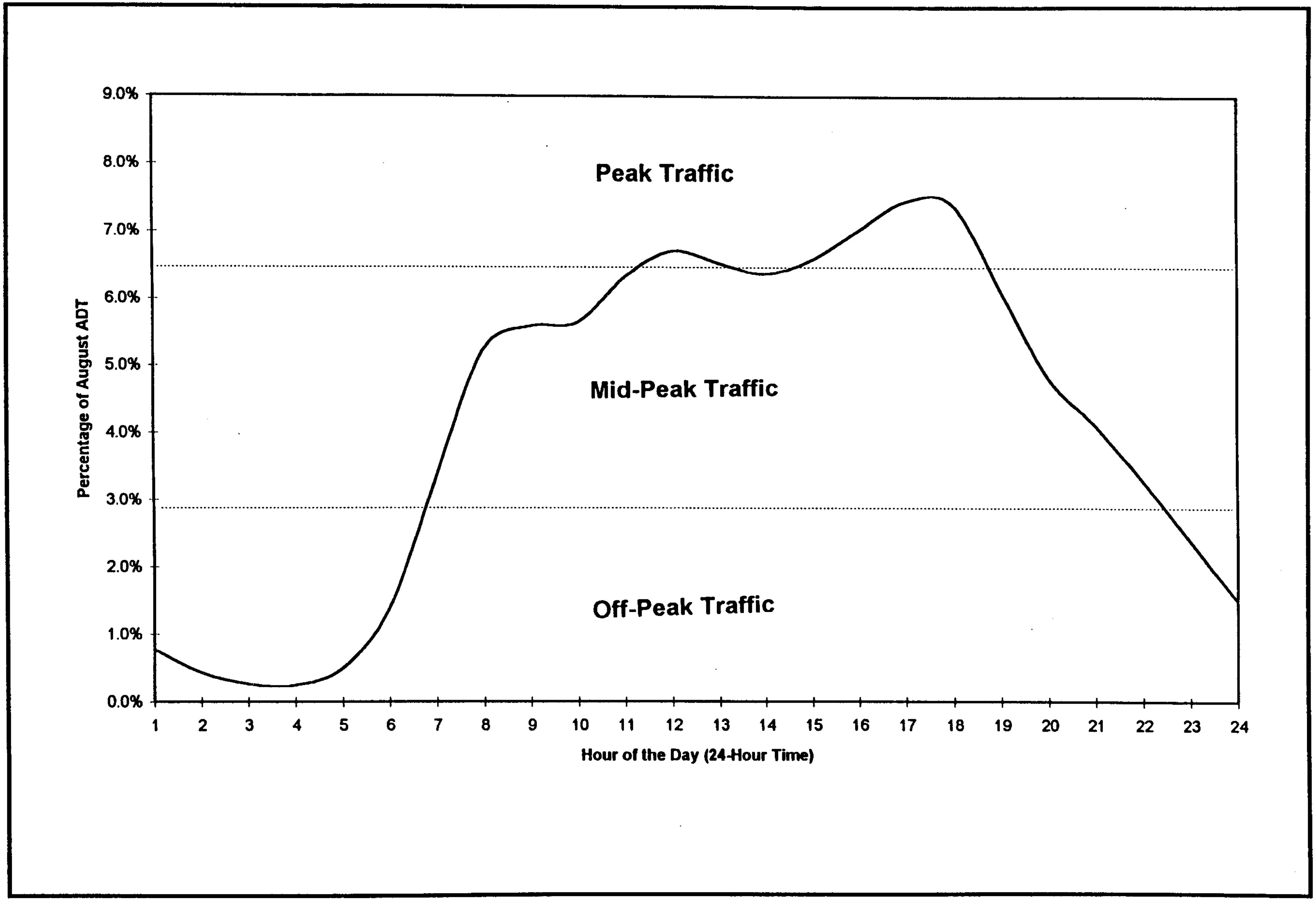

Figure 6.2b Weighted Average of Hourly ADT Along Major Routes in Southern Massachusetts - Cape Cod Road Network.

spots where the average daily traffic was correlated. The model was assumed to be calibrated when the volume of vehicles on each of the 26 links matched its corresponding actual 2-way average daily traffic by ±10% for Principal Arterials and ±15% for Major Collectors, and the distribution of hourly traffic approximated actual conditions.

6.5 DEVELOPMENT OF TRAFFIC DATA

6.5.1 Classification of Motorists

After road networks were developed and calibrated, the next steps of the analysis were to estimate the total number of vehicles that will load onto roadways over the course of an evacuation, and to determine the rates at which they will load onto roadways. To develop this information, motorists were classified as belonging to one of the four major groups listed below:

(1) Surge Vulnerable Evacuees: Permanent and seasonal residents living in evacuation zones who evacuate when directed to do so by authorities.

(2) Non-Surge Vulnerable Evacuees: Permanent and seasonal residents, excluding mobile home residents, living outside evacuation zones who choose to evacuate. Most of the evacuees of this category leave their homes because of perceived dangers and not necessarily because of real flooding threats. However, in some cases, officials may deem it necessary to evacuate small groups of people who live in substandard housing units particularly vulnerable to hurricane winds, or those who live in or near areas that may be exposed to freshwater flooding.

(3) Mobile Home Evacuees: All permanent and seasonal mobile home residents of coastal communities. It was assumed that all mobile home residents will be told to evacuate by local officials due to the high risk of wind damage from hurricanes of even modest intensity.

(4) Background Vehicles: The population associated with all remaining vehicle trip purposes. Examples are: Trips made by people who leave work early and return home, people who travel through the region, and trips made by persons preparing for the arrival of hurricane conditions or engaged in normal activities.

The number of evacuees from each group that is assumed to participate in an evacuation is important for estimating roadway clearance times. Behavioral information developed in the Behavioral Analysis gives estimates of the evacuation rates that can be expected for the first three groups. The fourth group, background vehicles, is not addressed by the Behavioral Analysis. However, this group is accounted for by the average daily traffic distribution shown in Figures 6.2(a) and (b).

Tables 4.2 and **4.3** list the estimated number of permanent and seasonal persons and mobile home residents that can be expected to evacuate for a given hurricane threat. **Table 4.2** refers to evacuations for a weak hurricane scenario, and **Table 4.3** refers to evacuations for a severe hurricane scenario. Estimates of the evacuating population were made by applying evacuation participation rates shown in **Table 4.1** to the vulnerable population listed in **Tables 3.1** and **3.2**.

6.5.2 Evacuee Destinations

Although the specific evacuee destinations and evacuation routes used by motorists are difficult to predict, the transportation model attempted to simulate the general geographic locations at which evacuees will exit the road network during evacuations. The preferences of background vehicles and evacuating vehicles to travel on a particular route in the model were assumed to be related to the traffic volume on that route during a normal August weekday. However, that assumption does not define the geographic locations at which evacuees will exit the road network. The following paragraphs present the information used to determine the destination of evacuees to be used in the transportation model.

The main source of information used for guidance in deriving general evacuation destinations was the Behavioral Analysis. The Behavioral Analysis concluded the following based on actual evacuee response data collected after Hurricane Gloria in 1985.

(1) In the northeast states, 55-79% of the evacuating population stay within their community.

(2) In the northeast states, between 83 and 100% of the evacuating population reach their destination in approximately 30 minutes.

(3) In the northeast states, between 3 and 23% of the evacuating population use public shelters.

In addition, the Federal Emergency Management Agency (FEMA) has a standard for public sheltering at 20 percent of the threatened population. The Corps of Engineers held a meeting with the Massachusetts Emergency Management Agency and the Corps transportation consultant to discuss the assumptions to be used for evacuee destinations in the transportation analysis. After considering the above information, along with the characteristics of the southern Massachusetts area, the parties jointly determined the following:

> (1) For both the Buzzards Bay and Cape Cod networks, assign 15% of the evacuating population to exit nodes corresponding to public shelters within the community. Fifteen percent is reasonable, since this study assumes that the following percentages of the evacuating population will seek public shelter (see **Table 4.4**): 10% of those evacuating Evacuation Zone "A"; 20% of those evacuating Evacuation Zone "B"; 100% of mobile home residents; and 20% of the non-surge vulnerable population. Also, since this study assumes that a high percentage of threatened population and a small percentage of the non-threatened population will evacuate, 15% of the evacuating population is close to the 20% of the threatened population recommended by FEMA.
>
> (2) For the Buzzards Bay network, assign 40% of the evacuating population to exit nodes within the community from which they evacuate. Because of the high proportion of tourist traffic on Cape Cod, 25% of the evacuating population was assigned to this category for the Cape Cod network. For both networks, this brings the total evacuating population which stays within their community to 55% and 40% respectively. For the Buzzards Bay network, this is consistent with the estimated 55-79% of evacuees that were assumed to stay within the community in the northeast states. The lower Cape Cod network percentage of 40% reflects the high proportion of tourist evacuee traffic.
>
> (3) For the Buzzards bay network, assign 25% of the evacuating population to exit nodes outside the affected communities but within 15 miles of the coast (corresponding to a 30 minute travel time). For the Cape Cod network, 20% of the evacuating traffic was assigned to this category. This brings the total within 30 minutes travel time up to 80% for the Buzzards Bay network. The total up to this category for the Cape Cod network is 60%. Because of the restricting nature of the Bourne and Sagamore bridges, the assumed travel time for the 15 mile drive is probably on the order of 1-2 hours rather than 30 minutes.
>
> (4) For the Buzzards Bay network, assign 20% of the evacuating population to exterior exit nodes, roughly 15 miles or more from the inundation areas. Because of the high proportion of tourist traffic on Cape Cod, 40% of the evacuating population in the Cape Cod network was assigned to this category.

After each evacuation simulation was run, exit node departures reported by NETVAC2 were checked to verify that the modeled evacuee destinations agreed with the destinations described above.

6.5.3 Behavioral Response of Motorists

Perhaps one of the most critical assumptions that must be considered when estimating roadway clearance times is at what time evacuees will load onto roadways relative to an evacuation advisory being disseminated to the public. Research obtained from past hurricane evacuations shows that mobilization and actual departures of the evacuating population occur over a period of many hours and sometimes several days. For the southern Massachusetts study area, evacuation simulations were tested for three roadway loading rates that are summarized by the evacuee response curves shown in Figure 4.2. The evacuee response curves describe the percentages of the evacuating population who leave their homes and load onto roadways at hourly intervals relative to when an evacuation recommendation is disseminated to the public.

The evacuee response curves are intended to include the most probable range of evacuee response times that can be expected in a future hurricane evacuation in southern Massachusetts: rapid response, moderate response, and slow response. The rapid response curve depicts the quickest mobilization response by evacuating households. The rapid response curve assumes that evacuees begin to load onto roadways to evacuate two hours before an evacuation recommendation is disseminated to the public, and stop loading onto roadways four hours after it is disseminated. For the moderate response curve, it is assumed that evacuees begin to load onto roadways three hours before dissemination of the evacuation recommendation, and stop loading onto roadways six hours after. The slow response curve assumes that evacuees start loading onto roadways four hours prior to dissemination of the evacuation recommendation, and stop loading eight hours after.

The public's response before an evacuation recommendation is given accounts for people who choose to evacuate their homes before being directed to do so by authorities. Some evacuate early in response to televised weather forecasts, and some evacuate early in to get ahead of the bulk of evacuating traffic. In previous hurricane evacuations, it was found that people's timeliness in responding to a hurricane evacuation was dependent on the aggressiveness of authorities in encouraging them to leave. Therefore, for all three evacuee response curves, only 15% of those who will eventually evacuate are assumed to evacuate prior to the dissemination of an evacuation recommendation, while 85% of those who will eventually evacuate are assumed to evacuate after dissemination of an evacuation recommendation.

For Hurricane Edouard, which was forecasted to strike New England over Labor Day weekend in 1996, many people chose to evacuate Cape Cod, even though no community evacuation recommendations were issued (only state parks and campgrounds were officially told to evacuate). Most of the early evacuees likely chose to evacuate on their own since it was near the end of the weekend, and the weather was forecasted to deteriorate. Since each hurricane forecasted to strike New England will have a unique set of circumstances, each evacuation will produce a unique evacuation response.

6.5.4 Vehicle Usage

In the Behavioral Analysis, it was estimated that approximately 75 percent of the vehicles available to evacuees will be used during evacuations. For the most part, families usually evacuate using one vehicle for fear of separation, but some households evacuate using two or more vehicles depending on how many are available to them.

The first column of **Table 6.1** lists the permanent population by community for coastal communities in Massachusetts. The second and third columns list the numbers of available vehicles per owner and renter-occupied housing units, respectively. This information was obtained from the 1990 census. The third column lists the number of available vehicles per person, and the fourth column lists the calculated average number of people that will travel in each evacuating vehicle, assuming that 75 percent of the available vehicles are used. A sample calculation for the town of Barnstable, Massachusetts is shown below.

$$\textit{Permanent population} = 40{,}950$$

$$\textit{Available vehicles} = 21{,}080 + 6{,}000 = 27{,}080 \textit{ vehicles}$$

$$\textit{Vehicles per person} = \frac{27{,}080 \textit{ vehicles}}{40{,}950 \textit{ people}} = 0.66 \frac{\textit{vehicles}}{\textit{person}}$$

$$\textit{Persons per evacuating vehicle} = \frac{1}{0.66 \frac{\textit{vehicles}}{\textit{person}} x \; 0.75}$$

$$= 2.02 \frac{\textit{persons}}{\textit{vehicle}}$$

The transportation analysis used the information in **Table 6.1** to determine the number of vehicles that would load onto roadways during evacuations from estimates made of the evacuating population. The user enters the vehicle occupancy rates and the number of people assigned to enter the network at each node. NETVAC2's complimentary program, POPDIS, aggregates the population input for each entry node and in turn computes the effective average vehicle loading rates per minute to be input into NETVAC2 at network entry locations.

TABLE 6.1(a)
BARNSTABLE COUNTY
ASSUMED VEHICLE USAGE RATES BY COMMUNITY

Community	Permanent Population	Available Vehicles in Owner Occupied Housing Units	Available Vehicles in Renter Occupied Housing Units	Vehicles Per Person	Persons Per Evacuating Vehicle (75% Usage)
Barnstable	40,950	21,080	6,000	0.66	2.02
Bourne	16,060	7,090	3,030	0.63	2.12
Brewster	8,440	4,800	1,160	0.71	1.88
Chatham	6,580	3,810	800	0.70	1.90
Dennis	13,860	7,290	2,230	0.69	1.93
Eastham	4,460	2,550	810	0.75	1.78
Falmouth	27,960	14,510	4,220	0.67	1.99
Harwich	10,280	5,980	1,320	0.71	1.88
Mashpee	7,880	3,900	1,300	0.66	2.02
Orleans	5,840	3,240	1,040	0.73	1.83
Provincetown	3,560	1,100	770	0.53	2.52
Sandwich	15,490	9,120	1,480	0.68	1.96
Truro	1,570	990	260	0.80	1.67
Wellfleet	2,490	1,500	480	0.80	1.67
Yarmouth	21,170	11,140	3,520	0.69	1.93

TABLE 6.1(b)
BRISTOL COUNTY
ASSUMED VEHICLE USAGE RATES BY COMMUNITY

Community	Permanent Population	Available Vehicles in Owner Occupied Housing Units	Available Vehicles in Renter Occupied Housing Units	Vehicles Per Person	Persons Per Evacuating Vehicle (75% Usage)
Acushnet	9,550	5,820	690	0.68	1.96
Dartmouth	27,240	13,970	2,180	0.59	2.26
Fairhaven	16,130	7,840	2,290	0.63	2.12
Fall River	92,700	20,450	24,590	0.49	2.72
New Bedford	99,920	27,130	19,430	0.47	2.84
Rehoboth	8,660	5,730	520	0.72	1.85
Seekonk	13,050	8,730	820	0.73	1.83
Somerset	17,660	10,800	1,540	0.70	1.90
Swansea	15,410	9,930	800	0.70	1.90
Westport	13,850	8,510	1,480	0.72	1.85

TABLE 6.1(c)
PLYMOUTH COUNTY
ASSUMED VEHICLE USAGE RATES BY COMMUNITY

Community	Permanent Population	Available Vehicles in Owner Occupied Housing Units	Available Vehicles in Renter Occupied Housing Units	Vehicles Per Person	Persons Per Evacuating Vehicle (75% Usage)
Marion	4,500	2,450	700	0.70	1.90
Mattapoisett	5,850	3,300	800	0.70	1.90
Rochester	3,920	2,670	100	0.71	1.88
Wareham	19,230	9,600	2,280	0.62	2.15

6.6 EVACUATION SCENARIOS

Since all hurricanes differ from one another in some respect, it becomes necessary to set forth clear assumptions about storm characteristics and evacuees' expected response before evacuation simulations are run. Not only does a storm vary in its track, intensity, and size, but also in the way it is perceived by residents in potentially vulnerable areas. These factors can cause a wide variance in the behavior of the vulnerable population. Even the time of day at which a storm makes landfall influences the response time of the evacuating population.

Clearance times were calculated for a range of evacuation scenarios, representing many possible situations officials may have to contend with. The three major parameters that were varied with each simulation are described below.

(1) Hurricane Severity: Storms are classified as either weak or severe hurricanes. The population expected to evacuate a severe hurricane is significantly greater than the population expected to evacuate a weak hurricane (see **Tables 4.2 and 4.3**). Descriptions of weak and severe hurricane scenarios are given in detail in Chapter Three and correspond to the evacuation zones identified in the companion Evacuation Map Atlas.

(2) Evacuee Response: The amount of time it takes evacuees mobilize to leave their homes and enter onto the roadway system is characterized by the evacuee response curves shown in **Figure 4.2**. Response curves are defined for rapid, moderate, and slow evacuee responses.

(3) Background Traffic Condition: The traffic condition at the start of an evacuation will depend on the time of day the evacuation begins as well as other factors that may influence initial traffic conditions. Initial traffic conditions corresponding to peak, mid-peak, and off-peak average daily traffic levels were analyzed.

The Transportation Analysis simulated evacuations occurring during rush hour by programming evacuees to load onto roadways that were initially set at peak average daily traffic volumes. Conversely, an evacuation occurring at times of light traffic, such as late at night or early in the morning, was modeled by running the model with background conditions initially set at off-peak average daily traffic volumes. Simulations run with background traffic at mid-peak average daily traffic volumes represented moderate traffic volumes typical of late morning or early afternoon on weekdays or on weekend days.

A key point in using Figure 6.2 to derive background traffic conditions is that all traffic conditions are derived from actual traffic patterns observed for roadways in the Buzzards Bay and Cape Cod networks, respectively, rather than from assumed hypothetical conditions. Figures 4-1 and 4-2 in Appendix D show the off-peak, mid-peak, and peak background traffic distributions which were used for the Buzzards Bay and Cape Cod networks, respectively.

Combinations of the three key input parameters listed above were used in developing 18 possible evacuation scenarios for each network. The 18 scenarios consisted of all combinations of: weak and severe hurricanes; off-peak, mid-peak, and peak background traffic; and slow, moderate, and rapid evacuee response.

6.7 EVACUATION SIMULATION RESULTS

6.7.1 General

Clearance time and dissemination time are two factors which should be considered when deciding when an evacuation recommendation/order should be issued. The combination of these times defines a region's total evacuation time. Clearance time begins when an evacuation order/recommendation is clearly disseminated to the threatened public and ends when the last evacuees clear the road system. This time includes the time required by evacuees to secure their homes and prepare to leave (mobilization time), the time spent by evacuees traveling along the road network (travel time), and the time lost due to traffic congestion (queuing delay time). Clearance time does not relate solely to the time any one vehicle spends traveling on the road system.

Dissemination time is the amount of time required by officials to notify the public to evacuate after the decision to evacuate has been made. This amount of time is subjective and may differ by region depending on the communication and warning procedures utilized by State and local officials in a particular area. The times calculated by the Transportation Analysis include only the clearance time component of evacuation time, and officials using this information must determine the dissemination time appropriate for their areas. Failure to add dissemination time to clearance time will underestimate total evacuation time, which could result in insufficient time for all evacuees to safely clear the hazard area.

Evacuations should be completed before the arrival of gale force winds (34 knots/39 mph) and/or storm surge. Vehicle accidents and reduced travel speeds from inclement weather can impede traffic flows, and potentially disrupt an evacuation. Therefore, the transportation analysis assumes that evacuations will occur well enough before a hurricane to preclude delays caused by significant weather. Moreover, the analysis assumes that provisions would be made for removal of vehicles in distress during an evacuation. The Decision Arc Method outlined in Chapter Eight explains how clearance times, used in conjunction with dissemination times specified by officials, can be used for guidance in hurricane evacuation decision making. The time at which gale force winds arrive is incorporated into the Decision Arc Method and therefore is not factored into the calculation of clearance time.

6.7.2 Clearance Times

Tables 6.2 and 6.3 present the clearance times estimated for the Buzzards Bay and Cape Cod networks for weak and severe hurricane scenarios, respectively. Times are organized by intensity of hurricane, by rate of response of the evacuating population, and by level of background traffic at the start of evacuations.

The clearance times were calculated assuming that each community is capable of sheltering its individual demands and no shelter capacity deficiencies exist. The Transportation Analysis tested how inadequate shelter capacity might influence roadway clearance times by comparing computed clearance times using two levels of shelter availability. Results showed that deficiencies in shelter capacity have a minimal effect on roadway clearance time. This point is explained by the fact that the numbers of vehicles estimated to travel to public shelters is very small in comparison to all vehicles on roadways. Consequently, the clearance times provided in **Tables 6.2 and 6.3** are considered valid for the existing condition of sheltering deficiencies in some communities and in the future if community sheltering capabilities increase.

TABLE 6.2
SUMMARY OF CLEARANCE TIMES (Weak Hurricane Scenario)

	BACKGROUND TRAFFIC		
	Off-peak	Mid-peak	Peak
BUZZARDS BAY NETWORK	Hrs.	Hrs.	Hrs.
Rapid Response (4 hours)	4½	5¼	5½
Moderate Response (6 hours)	6½	6½	7
Slow Response (8 hours)	8	8½	8¾
CAPE COD NETWORK			
Rapid Response (4 hours)	6¼	7½	9¼
Moderate Response (6 hours)	7	9¼	10¾
Slow Response (8 hours)	8¾	10½	12½

Notes: 1. Dissemination time must be added to clearance time to estimate total evacuation time.
2. Clearance time rounded to the nearest quarter hour.

TABLE 6.3
SUMMARY OF CLEARANCE TIMES (Severe Hurricane Scenario)

	BACKGROUND TRAFFIC		
	Off-peak	Mid-peak	Peak
BUZZARDS BAY NETWORK	Hrs.	Hrs.	Hrs.
Rapid Response	5	5½	5¾
Moderate Response	6¾	7	7½
Slow Response	8¼	8¾	9
CAPE COD NETWORK			
Rapid Response	8	8½	10
Moderate Response	8¼	9¾	11½
Slow Response	9¼	11¼	13

Notes: 1. Dissemination time must be added to clearance time to estimate total evacuation time.
2. Clearance time rounded to the nearest quarter hour.

Buzzards Bay Network

Results for the Buzzards Bay network show that clearance times are estimated to range from 4½ to 9½ hours. Clearance times for the four Bristol County communities of Seekonk, Rehoboth, Swansea, and Somerset were calculated in the Rhode Island Hurricane Evacuation Study. The clearance times for those communities were compared to the clearance times shown in **Tables 6.2 and 6.3**. It was found that most times for corresponding scenarios were within 30 minutes, and all times were within 45 minutes. Therefore, it is recommended that the times shown in **Tables 6.2 and 6.3** be used for those four communities as well.

Clearance times in **Tables 6.2 and 6.3** are organized by level of background traffic at the start of evacuations, by intensity of hurricane (which dictates the level of evacuating traffic), and by evacuee response time. The relative significance of background traffic, evacuating traffic, and evacuee response time is explained below.

For this network, the roadway clearance times for off-peak and mid-peak conditions under both weak and severe hurricane scenarios are only slightly greater than the evacuee response times. This indicates that evacuee response time is the primary factor influencing roadway clearance time for the Buzzards Bay network.

Evacuating traffic experiences basically free flow conditions for all three evacuee response scenarios. The exceptions are Routes 24 and 6 through Fall River, and Route 6 through New Bedford. Along these routes, the congestion corresponds to the loading intervals for evacuating traffic.

Influence of Background Traffic on Clearance Times

The ratio of evacuating to background traffic in the Buzzards Bay network is comparable to that of the Rhode Island study networks. Since there is a relatively high roadway capacity in this network, background traffic clears relatively easily compared to the Cape Cod network. Only during peak conditions is capacity exceeded enough to cause delays. This observation leads to the conclusion that background traffic has an appreciable influence on roadway clearance times only during peak background traffic conditions.

Influence of Evacuating Traffic on Clearance Times

Since there is sufficient roadway capacity in the off-peak and mid-peak conditions to handle both background and evacuating traffic with delays of one hour or less, the volume of evacuating traffic does not have an appreciable impact on roadway clearance times. During peak background traffic conditions, the network capacity is sufficiently strained by the evacuating traffic to cause delays of up to 1 hour and 45 minutes. This means that the evacuating traffic volume is the main cause of delays during peak background traffic conditions.

Comparison of roadway clearance times for the weak and severe hurricane scenarios shows that there is sufficient roadway capacity in the off-peak and mid-peak conditions to handle both levels of evacuating traffic. During peak background traffic conditions, the network capacity is strained during both the weak and strong scenarios, leading to the conclusion that evacuating traffic is the main cause of delays during peak background traffic conditions.

Influence of Response Time on Clearance Times

The variation of roadway clearance times once all evacuating traffic has been loaded on the network is one hour or less. This leads to the conclusion that evacuee response time is the main influence on roadway clearance times for all background conditions for the Buzzards Bay network. Results for the severe hurricane scenarios show greater congestion problems along Routes 24 and 6 in Fall River and Route 6 in New Bedford. This intermittent congestion also corresponds to the loading intervals for evacuating traffic.

For peak conditions under the weak hurricane scenario, and all conditions under the severe hurricane scenario, vehicle congestion is expected along portions of Route 24 and Route 6 in Fall River and Route 6 in New Bedford. Congestion is also predicted along connecting routes to Routes 24 and 6 in Fall River and New Bedford.

Summary

Clearance times in **Tables 6.2 and 6.3** are organized by level of background traffic at the start of evacuations, by intensity of hurricane (which dictates the level of evacuating traffic), and by evacuee response time. The relative significance of background traffic, evacuating traffic, and evacuee response time is summarized below.

Roadway clearance times for the Buzzards Bay network for most scenarios are governed by vehicle congestion. Congestion and vehicle queuing predicted along two major arterials in the vicinity of Fall River and New Bedford adds up to 1 hour and 45 minutes over the evacuee response time to the rapid response scenario. Analysis of estimated roadway clearance times shows that the difference in evacuating traffic between a weak and severe storm would add less than one hour to the total roadway clearance time. The only scenarios not governed by vehicle congestion are the off-peak and mid-peak, slow evacuee response conditions under both weak and severe hurricane scenarios, which are mostly defined by the evacuee response time.

Cape Cod Network

For the Cape Cod network, clearance times are estimated to range from 6¼ to 13 hours for evacuee response times ranging from 4 to 8 hours. Clearance times for the Cape Cod network were longer than for the Buzzards Bay network due to congestion near the Bourne and Sagamore Bridges as well as congestion along Routes 6 and 28 along the mid-Cape.

Clearance times in **Tables 6.2 and 6.3** are organized by level of background traffic at the start of evacuations, by intensity of hurricane (which dictates the level of evacuating traffic), and by evacuee response time. The relative significance of background traffic, evacuating traffic, and evacuee response time is explained below.

The roadway clearance times for all conditions are substantially longer than the evacuee response times, indicating that the evacuating traffic conditions are the primary factor influencing roadway clearance time for all conditions.

Evacuating traffic during the weak storm scenario for all three background traffic conditions produces slow traffic and queuing along sections of Routes 6 and 28 in Orleans, Brewster, Chatham (Route 28 only), Harwich, and Yarmouth (Route 28 only). Route 28 and its connector routes through Falmouth, Bourne and Wareham also experience congestion and low travel speeds of 15-30 mph. Speeds across the Bourne Bridge slow to 20-25 mph during peak traffic conditions due to traffic from Route 28.

Traffic on the Sagamore Bridge slows to around 35 mph during peak traffic conditions with significant congestion extending along Route 6 behind the bridge, especially in Yarmouth, Dennis, Harwich and Brewster. Speeds along Route 6A are consistently in the 25-30 mph range. Much of the observed intermittent congestion corresponds to the loading intervals for evacuating traffic, indicating that the intermittent congestion is directly related to the assumed rate at which evacuees load onto roadways. The same observations are true for the severe hurricane scenario, only the magnitude of the congestion and size of the queues in the same areas increases.

Influence of Background Traffic on Clearance Times

The ratio of evacuating traffic vehicles to background traffic vehicles for the Cape Cod network is the highest of all seven networks from the Rhode Island, Connecticut and Southern Massachusetts Hurricane Evacuation Studies. For the off-peak background condition, there is still enough capacity on the modeled roadway system to handle the volumes with delays of 2 hours or less. However, the increased background traffic volumes experienced during mid-peak background traffic conditions combined with the relatively high ratio of evacuating traffic compared to the other three networks results in capacity constraints being exceeded, and delays of over 3 hours are experienced. The situation worsens for the peak background condition where delays of up to 5 hours are experienced. Model simulations performed during the calibration of the model show that the network can clear within about six to seven hours of the end of traffic loading, which is consistent with the methodology used in the Rhode Island Study.

Influence of Evacuating Traffic on Clearance Times

As previously stated, the ratio of evacuating traffic vehicles to background traffic vehicles for the Cape Cod network is the highest of all seven networks from the three southern New England Hurricane Evacuation Studies completed to date. For the off-peak background condition, the addition of the evacuating traffic to the background traffic results in up to two hour delays. The addition of evacuating traffic to the mid-peak and off-peak background traffic conditions causes serious capacity exceedances that extend delays up to 5 hours. This observation leads to the conclusion that the addition of evacuating traffic has a much greater influence over roadway clearance times than does the background traffic. Comparison of the weak and severe scenario roadway clearance times also shows that increased evacuating traffic causes increased capacity exceedances and therefore influences roadway clearance times more than background traffic conditions. The difference in evacuating population between a weak and a severe storm, which increases the number of evacuating vehicles by approximately 30%, adds 30 minutes to 1 hour and 45 minutes to the roadway clearance time. This indicates that for all conditions, the volume of evacuating traffic is a substantial component of overall roadway clearance time.

Influence of Response Time on Clearance Times

For the Cape Cod network, clearance times exceed evacuee response times by 1½ to 6 hours in all cases, which is much greater than for the other three networks. The speed with which evacuees respond to an evacuation recommendation does not have as much of an influence on traffic congestion. The ratio of evacuating to background traffic is high compared to the other three networks, and the capacity of the major evacuation routes on Cape Cod cannot easily handle the background and evacuating traffic.

Summary

Roadway clearance times for the Cape Cod network for all conditions are greatly influenced by the volume of evacuating traffic under both weak and severe hurricane scenarios. This is especially true for peak background traffic conditions, where evacuating traffic can add up to 6 hours to the roadway clearance time.

6.8 SENSITIVITY ANALYSIS

6.8.1 General

A sensitivity analysis was performed for the Transportation Analysis to determine how much clearance times would change if certain parameters were changed (from their assumed values). The parameters that were changed in the sensitivity analysis are:

- Evacuating Population - How much will roadway clearance times change if the evacuating population is assumed to be 20% greater?

- Evacuee Response Time - How much will roadway clearance times change if it is assumed that evacuees will mobilize to evacuate in 2 hours instead of 4 hours?

- Shelter Utilization - How much will roadway clearance times change if evacuees do not seek community shelters, but instead choose to evacuate to other locations. This analysis was done for the Buzzards Bay network only?

- Traffic Control Measures - How much will roadway clearance times change if traffic control measures are implemented at the Bourne and Sagamore Bridge rotaries (Cape Cod network only)?

The intent of the sensitivity analysis was not to assess all conditions, but to evaluate a range of conditions which would define appropriate bounds from which conclusions for all conditions could be drawn. To limit the number of simulations, only scenarios that could be considered as defining the "upper" and "lower" bounds of roadway clearance time were considered. From the base condition results, these scenarios were determined to be rapid and slow evacuee conditions during off-peak and peak background scenarios. Simulations were first evaluated for the severe hurricane scenario. If a significant impact was found, the weak hurricane scenario was then evaluated.

6.8.2 Sensitivity to Increases in Evacuating Population

A sensitivity analysis was performed to determine how much roadway clearance times can be expected to change if the evacuating population is assumed to be 20% greater than shown in **Tables 4.2 and 4.3**. It was found that there was a moderate increase in roadway clearance times. The results are presented in Tables 5-3 and 5-4 of Appendix D. A 20% increase in evacuating population for the <u>severe hurricane scenario</u> was found to increase roadway clearance times 15 minutes to 1 hour for the Buzzards Bay network, and 15 minutes to 1 hour and 15 minutes for the Cape Cod network. The most significant increases were associated with the off-peak rapid evacuee response condition. For the <u>weak hurricane scenario</u> a 20% increase in evacuating population increased roadway clearance times by up to 45 minutes for both the Buzzards Bay and Cape Cod networks. For planning purposes, a 10% increase in evacuating population could be expected to increase roadway clearance times by a maximum of 1 hour.

6.8.3 Sensitivity to Reduced Rapid Response Time

A shorter rapid evacuee response time was evaluated to determine the sensitivity of roadway clearance time to the assumed rapid response time. A 2-hour decrease in rapid response time (or a total evacuee response time of 2 hours) was used for the sensitivity analysis, for the severe hurricane scenario. The results of the sensitivity analysis are shown in Table 5-5 in Appendix D.

Although evacuees were assumed to mobilize and start to evacuate 2 hours faster than in the base condition, roadway clearance times for both the Buzzards Bay and Cape Cod networks actually increased slightly. For both off-peak and peak conditions, the shorter evacuee response times increased roadway clearance times approximately 30 minutes from the base condition. The explanation is that roadway network and capacity constraints become more of a factor influencing total roadway clearance times when evacuees load the roadways in a shorter time.

6.8.4 Sensitivity to Reduced Shelter Utilization

An analysis was performed for the Buzzards Bay network to determine what impact reduced community shelter utilization could be expected to have on roadway clearance times. Reduced shelter utilization would produce a greater percentage of the evacuating vehicles traveling through the network, rather than exiting the network to shelters. This analysis was done only for the Buzzards Bay network since it was already assumed in the base condition that the population evacuating to community shelters on Cape Cod would be small in comparison to the population evacuating off-Cape.

The analysis was conducted assuming that only 75% of the evacuees assumed to use shelters under the base condition would actually use the shelters. The results, presented in Table 5-6 of Appendix D, indicate that the impact would be less than 30 minutes for all scenarios. It can be concluded that for most conditions under the severe hurricane scenario, the impact of a 25% reduction in community shelter use will not have an appreciable impact on roadway clearance times. It can also be concluded that for the weak hurricane scenario conditions, a reduction in community shelter use would generally have a smaller impa on roadway clearance times than for the strong storm scenarios.

6.8.5 Sensitivity to Traffic Control Measures

Analysis of the roadway clearance times for the 18 conditions modeled for the Cape Cod network showed that the capacity of the Bourne and Sagamore Bridges and their rotaries greatly influence roadway clearance times from the Cape. Consideration was given to modeling the Bourne and Sagamore Bridges with three lanes off Cape and one lane onto the Cape. However, this would not address bottlenecking at the rotaries, and does not allow for officials to limit the available routes to those which allow the most efficient flow of traffic.

Through coordination with the Massachusetts Emergency Management Agency and the Massachusetts State Police, it was determined that traffic flow could be improved at the rotaries during a hurricane evacuation by limiting turning movements. This can be expected to increase through-capacity and traffic speeds since competition will be reduced. The sensitivity analysis assumed the following:

- At the Bourne Bridge rotary, traffic from Routes 6 and 28 would be allowed to proceed north across the Bourne Bridge, but traffic from Trowbridge Road would be routed south on Route 28 and would turn north onto Route 28 at the Bourne landfill turn-off. Emergency vehicles would not be restricted. It is assumed that State Police would be stationed at the rotary, on Route 28 at the landfill turn-off, and at other locations as needed to facilitate traffic flow.

- At the Sagamore Bridge rotary, traffic from the bridge and Meetinghouse Road would be allowed to proceed around the rotary and onto Route 3 North. Traffic entering the rotary from the Bourne Scenic Highway would be required to exit the rotary at the first turn which would put them south-bound across the Sagamore Bridge. Emergency vehicles would not be restricted. It is assumed that State Police would be stationed at the rotary and at other locations as needed to facilitate traffic flow.

The results indicate that roadway clearance time can be significantly reduced by implementing the traffic control measures above (See Table 5-7 and 5-8 of Appendix D). For the peak, slow evacuee response conditions under the severe hurricane scenario, roadway clearance time was reduced by 1 hour 30 minutes. The reduction in roadway clearance time for the off-peak, rapid evacuee response scenario was 30 minutes, still significant enough to consider implementing the recommended traffic control measures at the Bourne and Sagamore Bridge rotaries. For the weak hurricane scenarios, the reduction in roadway clearance times were also significant but not as large (1 hour and 15 minutes for the peak, slow evacuee response condition, and 30 minutes for the off-peak, rapid evacuee response condition).

Chapter Seven

EVACUATION TIMES

7.1 INTRODUCTION

The Transportation Analysis developed clearance times for 18 evacuation scenarios each for the Buzzards Bay Network and the Cape Cod Network. Each scenario varied by hurricane intensity, evacuee response, and the level of background traffic at the start of the evacuation. A range of evacuation scenarios was used to quantify most of the evacuation situations officials may have to consider when deciding if, and when, an evacuation should be conducted.

To assist in implementing a coordinated state and local evacuation, it would be desirable for all southern Massachusetts communities to plan evacuations based on the same clearance time. However, because of the distinct difference in estimated clearance times for the Cape Cod communities and the off-Cape communities, it is recommended that evacuations be planned based on the characteristics of each of those two regions. That is, this study recommends one clearance time for the Cape and one clearance time for all other communities included in the study.

As noted in the Transportation Analysis, clearance time is one component of the total evacuation time. An additional time component, dissemination time, must be added to clearance time to determine the total time necessary to conduct a complete evacuation after the decision has been made to evacuate. This chapter further explains how evacuation times can be estimated from the clearance times developed in Chapter Six.

7.2 INFLUENCE OF BEHAVIORAL RESPONSE

The timing with which the threatened population evacuates in response to officials' warnings is a critical factor in whether or not an evacuation will be completed before the arrival of a storm. In the Transportation Analysis, three behavioral response curves, "slow", "moderate", and "rapid" rates of response were modeled in evacuation scenarios to address the uncertainty of public response. The following paragraphs qualify the clearance times developed from these rates of response.

Rapid behavioral response assumes that 85 percent of all evacuees will leave their homes within 4 hours of being directed to do so by officials (15 percent of the evacuees are assumed to leave before warnings are issued by officials). This curve represents the public's response in situations where people react quickly to aggressive warnings issued by officials. Clearance times derived from this assumed rapid response characterize evacuations where officials had not expected a hurricane to impact their locations, but the storm unexpectedly changed course and suddenly became a threat to the area. Other than this unusual "last minute" evacuation scenario, rapid public response of this nature is extremely optimistic, and should not be used for hurricane evacuation planning in southern Massachusetts. Statistics reported in the Behavioral Analysis (see Appendix B) show that people tend to mobilize and evacuate over longer periods of time than is assumed for a rapid evacuee response.

Evacuation scenarios based on rapid public response also yield clearance times which lack an acceptable margin of safety. For example, consider the scenario where the decision to evacuate is based on clearance times derived from the rapid behavioral response curve. If, during this scenario officials delay in making evacuation recommendations to the public, or the hurricane unexpectedly accelerates, there may not be enough time to complete the full evacuation prior to the storm's arrival. Because clearance times based on rapid behavioral response offer little margin of safety, the Corps of Engineers and FEMA recommend that evacuation decisions not be based on clearance times assuming a rapid evacuee response.

Slow evacuee response assumes that 85 percent of evacuees will mobilize and leave their homes over an 8-hour period after the public is made aware of the evacuation recommendation. This is probably longer than it would take the public to mobilize and leave their homes when evacuating during the daytime. The slow response is more representative of evacuations taking place late at night or early in the morning.

Moderate evacuee response assumes that 85 percent of evacuees will mobilize and leave their homes over an 6-hour period after the public is made aware of the evacuation recommendation. Such a response is likely most representative of evacuations taking place during the daytime hours. Evacuation decisions based on moderate response allow enough time to complete evacuations even if there is a delay in issuing warnings, or the storm unexpectedly accelerates.

Based on the above considerations and a review of hurricane evacuation studies developed for other east coast states, the Corps of Engineers and FEMA recommend that clearance times based on the moderate behavioral response be used for evacuation planning for daytime hurricane evacuations. However, if it appears that notices to evacuate will be given late at night or in the early morning; or if officials anticipate unusual delays in public response, then clearance times based on slow response should be used instead.

7.3 INFLUENCE OF BACKGROUND TRAFFIC

The amount of existing traffic (background traffic) on roadways at the start of an evacuation is another factor that can influence the safe completion of the overall evacuation. Background traffic is a measure of the vehicle trips by people who leave work early and return home, people who travel through the region, and trips made by people preparing for the arrival of hurricane conditions or engaged in normal activities. People who evacuate and travel on roadways to safe destinations (i.e., public shelters, friends'/relatives' homes, hotels/motels, etc.) are accounted for separately. The three levels of background traffic analyzed were off-peak, mid-peak, and peak traffic conditions.

Results from the Transportation Analysis (see **Tables 6.2 and 6.3**) show that clearance times for areas in southern Massachusetts are marginally affected by the level of background traffic at the start of evacuations, excluding the peak traffic condition. Also, excluding the peak traffic condition, modeling results show that clearance time is mostly a function of response time for evacuations occurring over a period of six hours or more. In these cases, the road system in southern Massachusetts is not restrictive in terms of the overall evacuation regardless of the severity of the approaching hurricane. However, as described in Chapter Six, intermittent pockets of congestion are predicted along several routes.

Traffic data collected for major roadways in New England on the days that Hurricanes Gloria and Bob made landfall indicate that it is unlikely that background traffic will be at peak levels on a day a hurricane is forecasted. <u>This is not to imply that the combination of evacuating and background traffic can not produce traffic conditions near, or worse than, normal peak volumes.</u> Should a hurricane be forecasted to landfall during the daytime, it is reasonable to expect that many commuters will not risk traveling to work, assuming public officials and employers discourage their attendance at work that day. News and weather forecasts will certainly discourage some employers from opening. Businesses that do open will probably shut down early, allowing people time to travel home before the storm arrives. The traffic data showed that hourly traffic volumes preceding evacuations for Hurricanes Gloria and Bob were lower than normal.

Consequently, it is reasonable to assume that mid-peak and off-peak background traffic conditions are more representative of the level of background traffic that will precede evacuations in southern Massachusetts. Clearance times based on background traffic levels near peak conditions may tend to overestimate clearance time.

7.4 RECOMMENDED CLEARANCE TIMES

The above sections attempt to qualify the 18 evacuation scenarios modeled in the Transportation Analysis for both the Buzzards Bay and Cape Cod road networks. Referring to the clearance times listed in **Tables 6.2** and **6.3**, by eliminating clearance times calculated for rapid response and those calculated for peak background traffic conditions, clearance times for Cape Cod range from 7 hours to 9¾ hours assuming moderate response time. For slow response, clearance times range from 8¾ to 11¼ hours. In all cases, the lower figure is for off-peak background traffic and a weak hurricane scenario, and the higher figure is for mid-peak background traffic and a severe hurricane scenario.

By eliminating clearance times calculated for rapid response and those calculated for peak background traffic, clearance times for all other study communities, represented in the Buzzards Bay Network, range from 6¼ hours to 7 hours assuming moderate response time. For slow response, clearance times range from 8 to 8¾ hours. In all cases, the lower figure is for off-peak background traffic and a weak hurricane scenario, and the higher figure is for mid-peak background traffic and a severe hurricane scenario.

For the Cape, a 10-hour clearance time is recommended for well-publicized evacuations occurring during the daytime; and an 11-hour clearance time is recommended for evacuations which occur late at night or early in the morning. For all off-Cape study communities, a 7-hour clearance time is recommended for well-publicized evacuations occurring during the daytime; and a 9-hour clearance time is recommended for evacuations which occur late at night or early in the morning. Emergency Management Officials may determine that it is appropriate to use clearance times developed from other scenarios if specific conditions warrant their use.

In southern Massachusetts, the decision to conduct an evacuation is an operational decision made at the community level. It is recognized that it would be useful to have one clearance time for all southern Massachusetts communities to assist in implementing a coordinated state and local evacuation. However, the transportation analysis showed that it is more realistic to use separate clearance times for Cape Cod and the off-Cape study communities. The use of separate clearance times for the Cape and the off-Cape study communities should help to eliminate potential discrepancies that might surface in evacuation decision-making from one community to the next. Furthermore, evacuation times which recognize the differences in clearance times for the Cape Cod and off-Cape road networks would allow for the most realistic evacuation planning.

As will be discussed in the next chapter, a hurricane evacuation should be completed prior to the arrival of sustained gale-force winds, or the onset of storm surge inundation, whichever occurs first. In southern Massachusetts, the constraining factor for the time an evacuation should be completed is the arrival of gale-force winds. The time at which gale-force winds are experienced in relation to eye landfall at a given location depends on the specific track of the hurricane and the symmetry of its radius of maximum winds about the eye. For the purposes of using the decision-making procedure outlined in the next chapter, the study makes a broad assumption that all southern Massachusetts locations, except the communities in Dukes and Nantucket counties, will experience gale-force winds at approximately the same time. Because the arrival of gale-force winds is the critical factor in determining when an evacuation must be completed, delays in the arrival of peak surge should not be factored into the time at which an evacuation is initiated.

7.5 CALCULATION OF EVACUATION TIME

Figure 7.1 illustrates the two components of evacuation time and the relationship of evacuation time to hurricane landfall. As shown, evacuation time starts once an evacuation decision is made and ends after the last evacuating vehicles clear roadways. Evacuation time is the sum of dissemination time and clearance time.

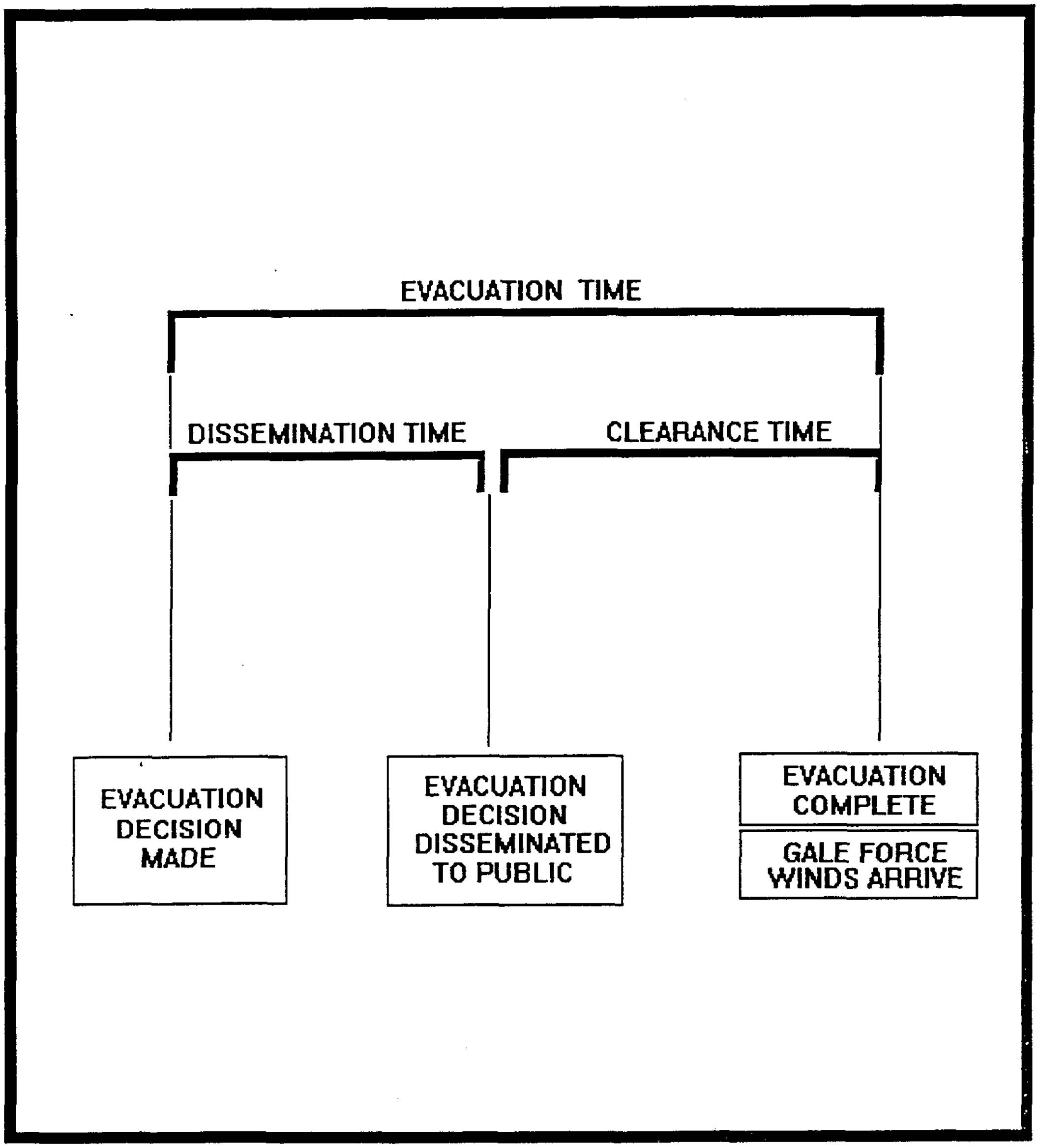

Figure 7.1 Components of Evacuation Time.

Dissemination time is the amount of time required by officials to notify the public to evacuate after the decision to evacuate is made. This includes the time required for emergency management officials to mobilize support personnel, coordinate the evacuation of all affected areas, and issue consistent warnings to the public. It is not reasonable to assume that once the State has made an evacuation recommendation to communities that all communities will immediately respond by issuing evacuation notices to the public. Dissemination time accounts for the necessary coordination time between State and local officials. However, dissemination time is not simply limited to this. Inherently, an amount of time is associated with mobilizing emergency officials within communities such that they can begin activating sirens, broadcasting warnings from emergency vehicles, and travel door to door to warn the public. Local warning plans may also include provisions for issuing advisories over the radio or on television, again requiring coordination time.

The hurricane preparedness procedures mentioned above are operational functions that vary from location to location. This study does not attempt to quantify dissemination time, but instead recommends that the Massachusetts Emergency Management Agency and the southern Massachusetts coastal communities determine dissemination times after thoroughly examining the State Warning Plan and their communication procedures.

One of the specific objectives of the Hurricane Bob Preparedness Assessment for Coastal Areas of Southern New England and New York, completed in May 1993, was to identify the roles, standard procedures, and communication systems the Massachusetts Emergency Management Agency and local communities use during hurricane emergencies. Officials are encouraged to refer to this document for important information and recommendations that can aid emergency management officials in quantifying dissemination time.

Failure to include dissemination time in the calculation of evacuation time will underestimate the time it takes to ensure a safe and complete evacuation. Once officials estimate a suitable evacuation time for a particular scenario, the Decision Arc Method of the next chapter can be used to determine if, and when, evacuation proceedings should be initiated.

7.6 EVACUATION PLAN FOR DUKES AND NANTUCKET COUNTIES

It is recognized that the evacuation rates in **Table 4.1** may not fully represent the complex evacuation situations of Martha's Vineyard, Nantucket, and Gosnold. The Steamship Authority shuts down ferry service when weather conditions jeopardize operations.[1] All people desiring to evacuate the islands may not be able to do so. This was observed during the evacuation prior to Hurricane Edouard over Labor Day weekend. These factors are difficult to figure into an evacuation analysis. Therefore, the evacuation rates shown in **Table 4.1** were used to estimate the number of evacuees from Martha's Vineyard, Nantucket, and Gosnold as well.

It is the intention of the communities of Dukes and Nantucket counties and the Massachusetts Emergency Management Agency to evacuate all non-permanent residents from the islands by ferry or other means possible in response to a hurricane threat. Shelter space will be provided on the islands for permanent residents, and those non-permanent residents who cannot be evacuated. Clearance times developed by the Southern Massachusetts Hurricane Evacuation Study do not apply to Dukes and Nantucket counties.

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[1]The Steamship Authority and the Massachusetts Emergency Management Agency are currently developing a contingency plan for natural disasters.

Chapter Eight

DECISION ANALYSIS

8.1 PURPOSE

The Decision Arc Method is a tool that uses a region's evacuation time in conjunction with National Hurricane Center advisories to calculate when evacuations must begin in order for them to be completed prior to the arrival of a hurricane's gale force winds. This chapter discusses the usefulness of the Decision Arc Method and provides a step-by-step procedure of how this method can be applied in Massachusetts.

8.2 BACKGROUND

The two meteorological parameters which determine a hurricane's point of landfall and the time it will arrive at its landfall location are its track and forward speed. These two parameters are inherently difficult to predict for hurricanes that impact New England.

Hurricanes moving from the tropics into the mid-Atlantic region encounter a dramatic change in steering currents, which usually results in a rapid acceleration of forward speed. It is difficult to predict when such an acceleration in forward speed will take place. This results in uncertainty in the expected time of landfall. Table 1.1 in Chapter One provides information on hurricanes passing within 125 statute miles of Boston, Massachusetts. Of the 20 hurricanes listed in the table, 13 of them (65 percent) accelerated to 25 mph or more, 10 (50 percent) accelerated to 35 mph or more, and 5 (25 percent) accelerated to 45 mph or more.

In situations where a hurricane is still hundreds of miles from the Massachusetts coast and forecasters are reasonably confident of the average forward speed the hurricane will travel, estimates of the time of landfall can be reasonably accurate. On the other hand, when weather officials are unable to make confident forecasts of a storm's forward speed, a great uncertainty exists in its time of landfall. For example, if a hurricane which is 360 miles from the coast suddenly accelerates from 30 mph to 40 mph, the hurricane would make landfall in 9 hours instead of 12 hours. Officials would have 3 hours less time to issue warnings and safely evacuate the public prior to the arrival of gale-force winds.

Hurricane track is similarly difficult to predict. From 1982 to 1991, the average error in the official 24-hour hurricane track forecast was 120 statute miles left or right of the forecasted track. The average error in the 12-hour official forecast was 62 statute miles. If a hurricane makes a slight shift in its direction of travel while still several hours away from its predicted landfall location, its actual landfall location may be more than one hundred miles from that originally forecasted. A one hundred mile deviation in landfall location might mean that a hurricane forecasted to pass out to sea may actually hit Cape Cod. Thus, what might appear to be a non-evacuation situation could quickly change to be an urgent evacuation scenario.

The combination of inaccuracies in hurricane forecasting and the lengths of the clearance times calculated for southern Massachusetts make hurricane evacuation decision-making a difficult task. Depending on a storm's average forward speed and the evacuation time estimated by officials for a particular storm scenario (see Chapter Seven), evacuations may have to be initiated while a storm is still hundreds of miles away. The decision to evacuate becomes more difficult when officials consider the uncertainty in a hurricane's forecasted track and the relatively low probability assigned by weather officials that a hurricane hundreds of miles away will strike a given location.

In spite of these uncertainties, evacuations must often be initiated even when the probability is low that a location will be impacted. It is recognized that the decision to start evacuations while storms are still several hours away is not an easy one. The information presented in this Chapter is designed to qualify some of the factors in evacuation decision-making to assist officials in using the data provided in this study in conjunction with National Hurricane Center forecasts for initiating evacuations.

8.3 DECISION ARC COMPONENTS

8.3.1 General

The Decision Arc Method employs two separate but related components which, when used together, depict the hurricane as it relates to coastal Massachusetts. A hurricane tracking chart called the Decision Arc Map, is teamed with a transparent storm disk to show the relation of the approaching hurricane to the coastline.

8.3.2 Decision Arc Map

In order to properly evaluate the last reported position and track of an approaching hurricane, a special hurricane tracking chart developed for southern Massachusetts is provided at the end of this chapter (see Figure 8.1). In Figure 8.1, a series of concentric arcs centered at Martha's Vineyard have been superimposed on a hurricane tracking chart. The arcs are spaced at 50 nautical mile intervals measured from their centers and labeled in nautical miles to correspond with the units given in National Hurricane Center advisories.

8.3.3 Storm Disk

The storm disk is used to represent an approaching hurricane. It is a transparent disk with concentric circles spaced at 25 nautical mile intervals, their center representing the hurricane's eye. These circles form a scale used to note the radius of 34 knot winds (gale force) reported in the National Hurricane Center's Tropical Cyclone Marine Advisory (Marine Advisory).

8.4 DECISION ARC METHOD

8.4.1 General

A hurricane evacuation should be completed prior to the arrival of sustained 34 knot (gale-force) winds, or the onset of storm surge inundation, whichever occurs first. In the southern Massachusetts study area, the constraining factor is the arrival of sustained 34 knot winds. Decision Arcs are simply evacuation times converted to distance by accounting for the forward speed and wind field of the hurricane. Multiplying the evacuation time by the hurricane's forward speed in knots translates evacuation time into nautical miles for use with a Decision Arc Map. This calculation yields the distance in nautical miles that the 34 knot wind field will move while the evacuation is underway. A Decision Arc table that converts evacuation times and forward speeds to Decision Arcs in nautical miles is provided in Table 8.3.

Evacuation time specifies when officials need to disseminate evacuation notices to the public to ensure that all evacuees have enough time to mobilize, evacuate their homes, and travel to their destinations before the arrival of sustained 34 knot winds. As discussed in Chapter Seven, evacuation time is the combination of clearance time and dissemination time. It is left up to State and local emergency management officials to determine the appropriate amount of time to disseminate the evacuation order to the public. **Tables 6.2 and 6.3** list the clearance times for southern Massachusetts developed for the most likely evacuation scenarios.

For Cape Cod, a 10-hour clearance time is recommended for well-publicized evacuations occurring during the daytime; and an 11-hour clearance time is recommended for evacuations which occur late at night or early in the morning. For all off-Cape study communities, a 7-hour clearance time is recommended for well-publicized evacuations occurring during the daytime; and an 9-hour clearance time is recommended for evacuations which occur late at night or early in the morning. Emergency Management Officials may determine that it is appropriate to use clearance times developed from other scenarios if specific conditions warrant their use.

8.4.2 Should Evacuation Be Recommended?

Probability values listed in the National Hurricane Center's Tropical Cyclone Probability Advisory (Probability Advisory) describe in percentages the chance that the center of a storm will pass within 65 nautical miles of the listed locations. To check the relative probability for a particular area, the total probability value for the closest location, shown on the right side of the probability table in the Advisories, should be compared to values given for other locations. A comparison should also be made with the maximum probability values listed in Table 8.3. There is no one threshold probability which should prompt an evacuation under any and every hurricane threat; the size and intensity of the storm, as well as its anticipated approach track, must also be considered.

8.4.3 When Evacuation Should Begin?

As a hurricane approaches, the Decision Arc Method requires officials to make an evacuation decision prior to the time at which the radius of sustained 34 knot winds intersects the appropriate Decision Arc (the Decision Point). As an example, for a hurricane with an average forward speed of 30 knots and a corresponding hypothetical evacuation time of 12 hours, the evacuation should be initiated before the sustained 34 knot winds approach within 360 nautical miles of the Massachusetts coast (12 hours x 30 nautical miles per hour = 360 nautical miles). The 360 mile distance can be interpolated between the "350" and "400" mile arcs on the Decision Arc Map. Once the sustained 34 knot winds move across the Decision Arc (or within 360 nautical miles of the

Massachusetts coast for this example), there may not be sufficient time to safely evacuate the affected population.

8.5 STEP-BY-STEP DECISION ARC PROCEDURE

The following procedure has been developed to provide assistance in determining IF an evacuation should be initiated and WHEN an evacuation decision must be made to ensure complete evacuation before sustained gale-force winds arrive. The hurricane probability listings provided in the Probability Advisory should be used to assist in this decision making process.

There are five basic "tools" needed in this evacuation decision procedure: (1) Decision Arc Map; (2) Decision Arc Table; (3) transparent storm disk; (4) the National Hurricane Center's Marine Advisory; (5) the National Hurricane Center's Probability Advisory.

PROCEDURE

1. From the National Hurricane Center's Marine Advisory, plot the last reported position of the hurricane eye on the Decision Arc Map. Notate the position with date/time. ZULU time ("Greenwich mean time" or "UTC" [Universal Coordinated Time]) used in the advisory should be converted to eastern daylight savings time by subtracting four (4) hours (see Table 8.4 for time conversions). Plot and notate the five forecast positions of the hurricane from the advisory.

2. From the Marine Advisory, note the maximum radius of 34 knot winds (either observed or forecast), the maximum sustained wind speed (either observed or forecast), and the current forward speed. Plot the maximum radius of 34 knot winds onto the storm disk.

3. Using the maximum sustained wind speed previously noted, use the Saffir/Simpson hurricane scale to determine the category of the approaching hurricane (see Table 8.1).

4. Estimate <u>evacuation time</u> by combining an appropriate <u>dissemination time</u> with the recommended <u>clearance time</u> **(evacuation time = dissemination time + clearance**

time). Dissemination time refers to the time officials need to make evacuation decisions, mobilize support personnel, communicate evacuation decisions between affected communities and the State, and disseminate evacuation directives to the public. Clearance time is defined as the amount of time required for all vehicles to clear roadways after a regional or state level hurricane evacuation recommendation is disseminated to the public.

5. Determine the forecast forward speed of the hurricane in knots. The forecast speed can be determined by measuring the distance in nautical miles between the first and second forecast positions and dividing that distance by 12 (forecast positions in the Marine Advisory are provided in 12 hour intervals). Compare the forecast forward speed to the hurricane's current forward speed. A forecast speed greater than the current forward speed will indicate that the hurricane is forecasted to accelerate, reducing the time available to the decision-maker.

6. With the appropriate evacuation time, and the greater of the current or forecasted forward speeds, enter Table 8.3 and determine the recommended Decision Arc in nautical miles. Mark this arc on the Decision Arc Map; interpolate between arcs as necessary.

7. Using the center of the storm disk to represent the eye of the hurricane, locate the storm disk on the Decision Arc Map at the last reported hurricane position. Determine if the radius of 34 knot winds falls within the selected Decision Arc (i.e., a location between the Decision Arc and your location). If so, public evacuation should be initiated in order to ensure a prompt public response and completion of the evacuation prior to the arrival of sustained 34 knot winds. Otherwise, if the radius of 34 knot winds lies outside of the selected Decision Arc, continue onto step number 8.

8. Move the storm disk to the first forecast position. Determine if the radius of 34 knot winds is past the Decision Point. If so, the Decision Point will be reached prior to the hurricane eye reaching the first forecast position.

9. Estimate the hours remaining before a decision must be made by dividing the number of nautical miles between the radius of 34 knot winds and the Decision Point by the

forward speed used for the Decision Arc table. Determine if the next National Hurricane Center Marine Advisory will be received prior to the Decision Point.

10. Compare probabilities shown in the Probability Advisory to determine whether an evacuation is now necessary, or is likely to become necessary (see Note c., below).

11. At the Decision Point, check the Probability Advisory for your location. There is no one threshold probability which should prompt an evacuation under any and every hurricane threat (see Note c., below). The size and intensity of the storm, as well as its approach track, must also be considered.

12. Steps 1 through 10 should be repeated after each National Hurricane Center advisory until a decision is made or the threat of hurricane impacts has passed.

<u>NOTES</u>:

a. As new information becomes available in subsequent National Hurricane Center advisories, evacuation operations should progress to ensure that, if evacuation becomes necessary, the recommendation to evacuate can be given at the Decision Point.

b. Because information given in the Marine Advisory is in nautical miles and knots, the Decision Arc Maps and storm disk have nautical mile scales. When utilizing hurricane information from sources other than the Marine Advisory, care should be taken to ensure that distances are in nautical miles and speeds are in knots. Statute miles can be converted to nautical miles by dividing the statute miles value by 1.15. Miles per hour can be converted to knots by dividing the miles per hour value by 1.15.

c. Probability values shown in the Probability Advisory describe in percentages the chance that the center of a storm will pass within 65 nautical miles of the listed locations. To check the relative probability for your particular area, the total probability value for the closest location, shown on the right side of the probability table in the Probability Advisory, should be compared to other locations. A comparison should also be made with the possible maximums for the applicable forecast period shown in Table 8.2. These comparisons will show the vulnerability of your location relative to adjacent locations and to the maximum possible probability.

TABLE 8.1
SAFFIR/SIMPSON HURRICANE SCALE WITH CENTRAL BAROMETRIC PRESSURE RANGES

CATEGORY	CENTRAL PRESSURE MILLIBAR	CENTRAL PRESSURE INCHES	WIND SPEED MPH	WIND SPEED KNOTS	SURGE FEET	DAMAGE POTENTIAL
1	>980	>28.9	74-95	64-83	4-5	Minimal
2	965-979	28.5-28.9	96-110	84-96	6-8	Moderate
3	945-964	27.9-28.5	111-130	97-113	9-12	Extensive
4	920-944	27.2-27.9	131-155	114-135	13-18	Extreme
5	<920	<27.2	>155	>135	>18	Catastrophic

TABLE 8.2
MAXIMUM TROPICAL CYCLONE PROBABILITY VALUES

FORECAST PERIOD	MAXIMUM PROBABILITY
72 Hours	10 %
60	11
48	13
36	20
30	27
24	35
18	45
12	60

Probabilities listed are the maximum assigned to any location in advance of predicted landfall. To illustrate: the National Hurricane Center would not assign a higher than 20% probability that a hurricane would strike Hyannis in 36 hours, or a higher than 35% probability that a hurricane would strike that location in 24 hours.

TABLE 8.3
DECISION ARCS

ESTIMATED EVACUATION TIME (HRS.)[1]	FORECAST HURRICANE FORWARD SPEED (KNOTS)[3]										
	10	15	20	25	30	35	40	45	50	55	60
	DECISION ARCS IN NAUTICAL MILES										
4[2]	40	60	80	100	120	140	160	180	200	220	240
5[2]	50	75	100	125	150	175	200	225	250	275	300
6[2]	60	90	120	150	180	210	240	270	300	330	360
7	70	105	140	175	210	245	280	315	350	385	420
8	80	120	160	200	240	280	320	360	400	440	480
9	90	135	180	225	270	315	360	405	450	495	540
10	100	150	200	250	300	350	400	450	500	550	600
11	110	165	220	275	330	385	440	495	550	605	660
12	120	180	240	300	360	420	480	540	600	660	720
13	130	195	260	325	390	455	520	585	650	715	780
14	140	210	280	350	420	490	560	630	700	770	840
15	150	225	300	375	450	525	600	675	750	825	900
16	160	240	320	400	480	560	640	720	800	880	960
17	170	255	340	425	510	595	680	765	850	935	1020
18	180	270	360	450	540	630	720	810	900	990	1080

NOTES:

[1] Evacuation time is the combination of dissemination time and clearance time. Refer to Chapter Seven, <u>Evacuation Times</u>, for more information on dissemination time and recommended clearance times.

[2] It is not expected that evacuation times of less than 7 hours will be used except in cases where a hurricane shifts direction or accelerates unexpectedly, or during evacuations where an unusual behavioral response is anticipated.

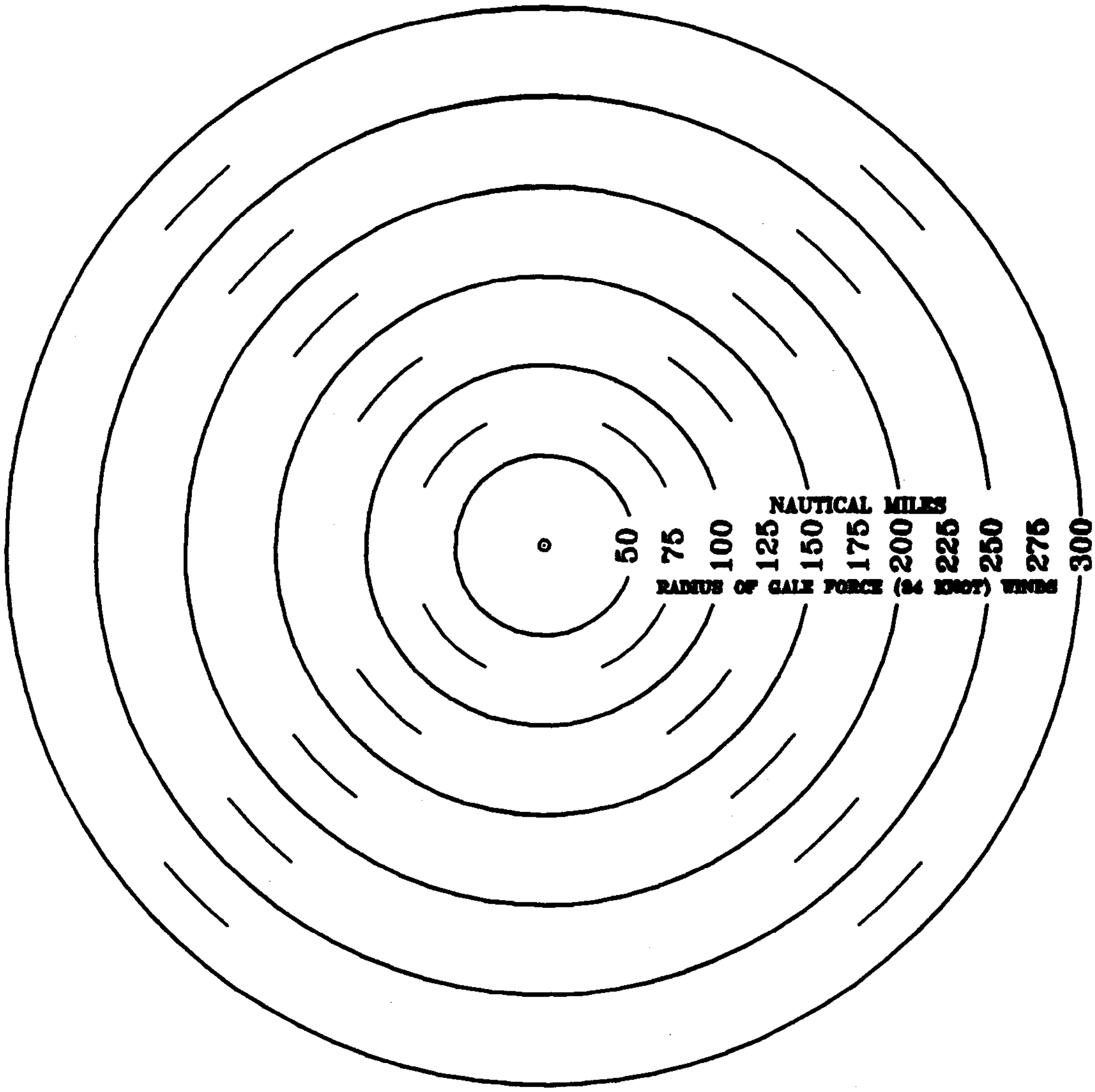
[3] Refer to steps 6 and 7 of the Decision Arc Procedure for methods of determining forecast forward speed.

TABLE 8.4
TIME CONVERSIONS

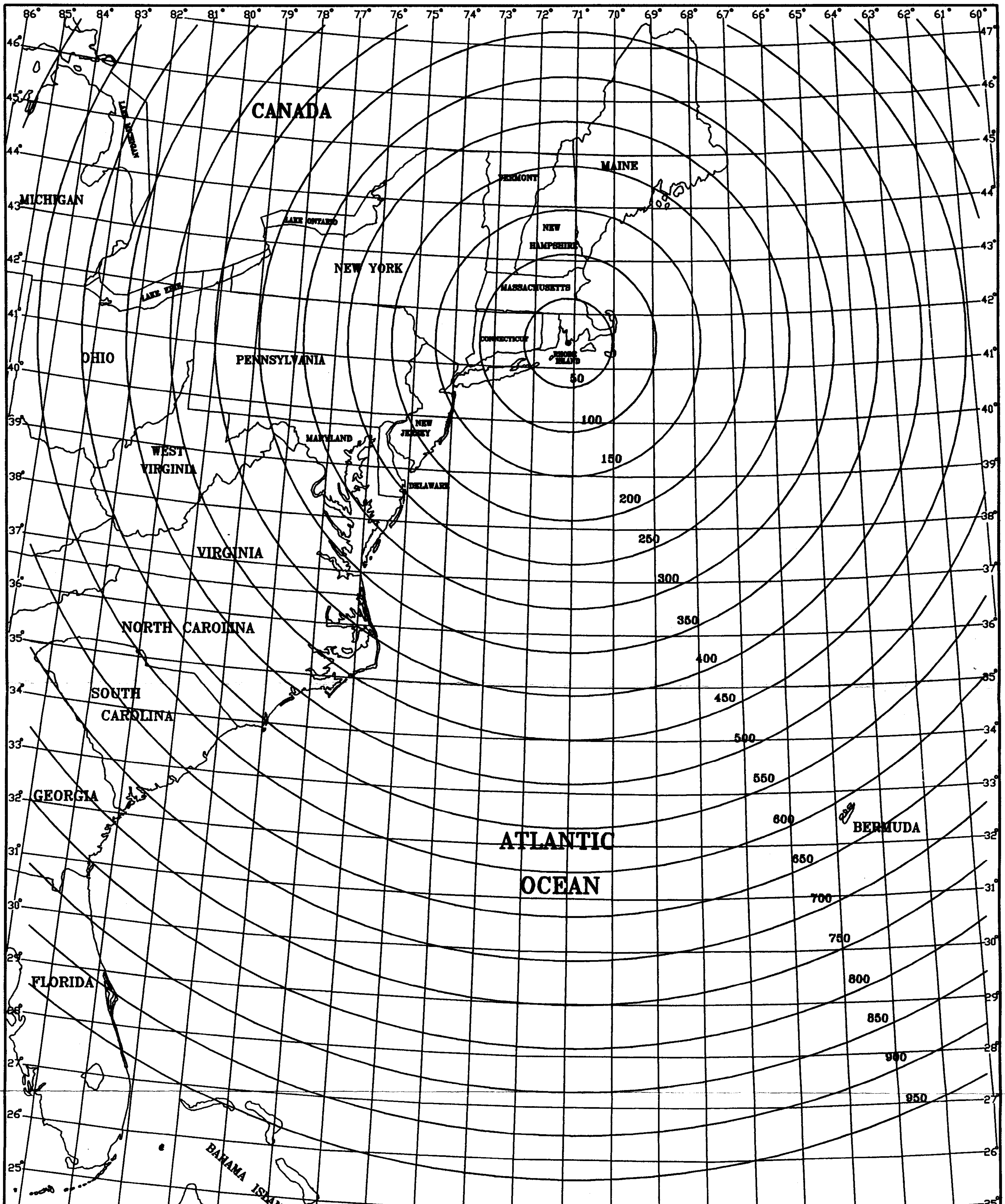
UNIVERSAL COORDINATED TIME (UTC)[2]	EASTERN DAYLIGHT SAVINGS TIME[1] (24 HOUR TIME)	CIVIL-TIME
0500 MONDAY	0100 MONDAY	1 AM MONDAY
0600	0200	2 AM
0700	0300	3 AM
0800	0400	4 AM
0900	0500	5 AM
1000	0600	6 AM
1100	0700	7 AM
1200	0800	8 AM
1300	0900	9 AM
1400	1000	10 AM
1500	1100	11 AM
1600	1200	12 NOON
1700	1300	1 PM
1800	1400	2 PM
1900	1500	3 PM
2000	1600	4 PM
2100	1700	5 PM
2200	1800	6 PM
2300	1900	7 PM
2400 (0000)	2000	8 PM
0100 TUESDAY	2100	9 PM
0200	2200	10 PM
0300	2300	11 PM
0400	2400 (0000)	12 MIDNIGHT
0500	0100 TUESDAY	1 AM TUESDAY

[1] For late season hurricanes (after 2:00 a.m. on the last Sunday in October) subtract 5 hours from Universal Coordinated Time to obtain Eastern Standard Time.

[2] UTC = Greenwich Mean Time = ZULU Time; it is expected that future National Hurricane Center advisories will reference "UTC."


NAUTICAL MILES
50
75
100
125
150
175
200
225
250
275
300
RADIUS OF GALE FORCE (34 KNOT) WINDS

STORM



SOUTHERN MASSACHUSETTS HURRICANE EVACUATION STUDY DECISION ARC MAP

SCALE: 100 50 0 100 200 Nautical Miles

Prepared by the U.S. Army Corps of Engineers, New England Division in cooperation with the Federal Emergency Management Agency, Region I for the Massachusetts Emergency Management Agency.

Figure 8.1 Decision Arc Map

Chapter Nine

SUMMARY

The purpose of this study is to provide the Massachusetts Emergency Management Agency and coastal communities in southern Massachusetts, including Cape Cod and the Islands, with data quantifying the major factors involved in hurricane evacuation decision-making. The results of this study are not intended to replace existing hurricane preparedness plans but rather to provide state-of-the-art information that can be used to update or revise current plans. This information includes the extent and severity of potential flooding, estimates of vulnerable population, public shelter locations and capacities, and roadway clearance times. The study also presents a step-by-step decision-making procedure outlining how this information can be used with National Hurricane Center advisories for hurricane evacuation decision-making.

In addition to this Technical Data Report and its appendices, the study developed two companion atlases: the <u>Inundation Map Atlas</u>, and the <u>Evacuation Map Atlas</u>. The <u>Inundation Map Atlas</u> delineates the land areas potentially vulnerable to worst case flooding for multiple hurricane scenarios. The <u>Evacuation Map Atlas</u> shows the evacuation zones developed for each community and presents the locations of public shelters and other critical facilities.

Throughout the report, several important assumptions and key points are made. The following paragraphs summarize some of the major steps completed in the study and re-emphasize many key points and assumptions.

In the Hazards Analysis, the National Hurricane Center applied the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) Model to the southern Massachusetts study area and calculated the flooding effects from several hundred hypothetical hurricanes. The focus of the modeling was to determine the maximum storm surges that could reasonably be expected from worst case combinations of hurricane parameters. For the southern Massachusetts study area, the height of peak surge at a particular location is significantly influenced by a hurricane's category and its forward speed.

Consequently, the study grouped worst case hurricane surges by hurricane category and forward speed. At each location in the study area, maximum surge elevations associated with critical hurricane tracks for each group were added to mean high tide elevations to estimate worst case storm tides. Category 5 hurricanes were omitted from the analysis by the National Hurricane Center because the cooler ocean waters of the northeast United States are not capable of sustaining a hurricane of Category 5 intensity. Historically, the most intense hurricane reported to have struck New England was the 1938 Hurricane, which researchers later classified as a strong Category 3 hurricane.

In the Hazards analysis, independent wave height and wave run-up analyses were conducted to determine the affects from waves on stillwater flood levels. At most locations, the analyses showed that there is a negligible increase in the stillwater flood level from wave effects. Wave heights along the coast and over the interior portions of the flooded land may be high, but as waves propagate and break farther inland, frictional losses diminish their contributions to flooding limits beyond stillwater levels. Storm tide elevation profiles were developed for the southern Massachusetts coast which graphically present the worst case stillwater levels that are possible for three hurricane category and forward speed dependent scenarios.

The Vulnerability Analysis used the worst case flood elevations determined from the Hazards Analysis to develop an Inundation Map Atlas for the State. This Atlas delineates the land areas that may become inundated from hurricane surge for the three flooding scenarios. A second atlas, the Evacuation Map Atlas, uses the flooding information from the Inundation Map Atlas to develop evacuation zones for each community. With the assistance of community officials, evacuation zones were delineated using the 1990 census block boundaries to aid in the development of vulnerable population estimates. The evacuation zone boundaries were selected such that they generally conform to known geographical features. The reason for this is that officials using these maps would be able to promptly and definitively convey to the public land area limits which should be considered for evacuation. Additionally, the names and locations of public shelters; medical/institutional facilities; and mobile homes/trailer parks and campgrounds are listed and shown in the Evacuation Map Atlas.

The Vulnerability Analysis determined that the State has approximately 205,000 residents potentially vulnerable to surge flooding during "weak hurricane scenarios" and approximately 288,000 residents potentially vulnerable to surge flooding during "strong hurricane scenarios". A Behavioral Analysis was performed to determine how the vulnerable population can be expected to respond in future hurricane threats. Factors investigated were: the percentage of residents that would leave vulnerable areas if directed to do so by authorities, the percentage of the evacuating population who would use public shelters, and the rates at which people would leave their homes once advised to do so. Behavioral assumptions were primarily derived using a "general response model" which qualitatively estimates human behavior during hurricanes based on behavioral information collected after many hurricanes occurring over the past three decades. Meetings were held with the State and communities to discuss and establish the behavioral assumptions that would be used for the study.

The next step of the study was the Shelter Analysis. In this analysis, behavioral assumptions and vulnerable population statistics were used to estimate the numbers of people in each community who could be expected to seek public shelters during a hurricane evacuation (shelter utilization). Estimates were made for two levels of hurricane threat, namely, the numbers of people who are expected to use public shelters during a "weak hurricane scenario" and during a "strong hurricane scenario". Communities and local American Red Cross chapters provided the names, locations and capacities of American Red Cross shelters and locally designated shelters. The Shelter Analysis determined that there appears to be an inadequate amount of public shelter capacity in several of the study communities. Those communities are encouraged to continue to work to identify additional public shelters.

It is important for hurricane evacuation decision-making to know how long it will take evacuating vehicles to clear roadways after the public is directed to evacuate. The Transportation Analysis used a numerical model of major roadways in southern Massachusetts to model hurricane evacuations. The model simulated evacuations and estimated roadway clearance times for 18 evacuation scenarios. Important factors that were varied with each simulation were: the intensity of the approaching hurricane, the response time of evacuees leaving their homes, and the background traffic condition at the start of the evacuation. In addition, the impact that increased population, reduced sheltering, traffic control measures, and reduced evacuee response time could have on clearance times was also determined.

Clearance times were found to range from 4½ hours to 13 hours depending on the above factors and the location within the State where the evacuation was modeled. Estimated roadway clearance times for Cape Cod were found to be longer than for other areas in coastal southern Massachusetts and also longer than the clearance times calculated for coastal communities in Connecticut and Rhode Island in prior Hurricane Evacuation studies.

Clearance times developed by the Southern Massachusetts Hurricane Evacuation Study do not apply to Dukes and Nantucket counties. It is the intention of the communities of Dukes and Nantucket counties and the Massachusetts Emergency Management Agency to evacuate all non-permanent residents from the islands by ferry or other means possible in response to a hurricane threat. Shelter space will be provided on the islands for permanent residents, and those non-permanent residents who cannot be evacuated.

Evacuation time is defined as the combination of roadway clearance time and dissemination time. Dissemination time includes time for officials to make evacuation decisions, mobilize support personnel, communicate between affected communities and the State, and disseminate evacuation directives to the public. Dissemination time will vary depending on established communication and decision making procedures of the State and communities. This study does not attempt to quantify dissemination time. Officials using the results of this study, after careful examination of their existing communication and warning procedures, must determine an appropriate amount of dissemination time. The Decision Analysis presents a step-by-step procedure that uses evacuation time and the National Hurricane Center's advisories for hurricane evacuation decision-making.

The completion of this multi-year study does not conclude the Corps of Engineers or the FEMA's involvement in hurricane preparedness activities in southern Massachusetts. The effectiveness of this study depends upon continued hurricane preparedness training and public awareness at all levels. FEMA and the Massachusetts Emergency Management Agency will incorporate the results of this study into their ongoing program of improving hurricane emergency management in Massachusetts. The following key points are emphasized to facilitate incorporation of this study's results into existing State and local hurricane preparedness plans.

1. Results from the SLOSH model show that storm surge generation in Massachusetts is significantly influenced by a hurricane's intensity category and its forward speed. The Hazards Analysis has shown that at most Massachusetts locations, surges which accompany fast moving Category 2 hurricanes (forward speeds greater than 40 mph) can generate surge levels close to or greater than the levels generated by more intense Category 3 or 4 hurricanes traveling at slower forward speeds (forward speeds of 20 mph or less). This phenomenon is caused by the increased wind stress on ocean water on the right side of the hurricane's eye from storms which travel at faster speeds. Consequently, it is important to understand that both the category and forward speed of an approaching hurricane are major factors in determining the storm's threat in terms of flood potential.

2. Errors in forecasting complicate hurricane evacuation decision-making, and it is important to recognize the forecasting capabilities and inherent limitations of hurricane forecasting by the National Weather Service. Even slight deviations in the forecasted track of a hurricane might mean a large difference in landfall location. The average error in a 12 hour hurricane forecast is approximately 60 miles. To illustrate how deviations from the forecasted track complicate evacuation decision-making, consider a hurricane that is forecasted to make landfall at the Rhode Island/Massachusetts border in 12 hours time. If this storm were to actually landfall anywhere between the vicinity of East Lyme, Connecticut and Chatham, Massachusetts, the resulting error in forecasted landfall location would be no worse than average. Stated another way, suppose that a hurricane that is forecasted to make landfall along the coast of Rhode Island in 12 hours actually hits Cape Cod directly, then its associated track error would be within error ranges typically forecasted. It follows from these examples that Massachusetts is potentially vulnerable to every hurricane forecasted to reach New England.

3. The New Bedford Hurricane Barrier, located in Clark Cove in New Bedford and in New Bedford Harbor in the communities of New Bedford and Fairhaven, provides a high degree of tidal-flood protection to an area of about 1,400 acres of heavily developed industrial and commercial properties along the waterfront and the Acushnet River. A review of the storm surge data calculated by the SLOSH model indicates that peak surges generated from categories 3 and 4 hurricanes, with forward speeds greater than 40 mph, may exceed the barrier's design elevation. Hurricanes that exceed the barrier's design height travel on a north-northwest to north-northeast track direction, peak surge arrives coincident with predicted mean high tide, and landfall at the critical location to produce

the highest level of storm surge at New Bedford. It is also assumed that the hurricane landfalls coincident with high astronomical tide. It is extremely unlikely that all critical meteorological and hydrological conditions will occur simultaneously at New Bedford. However, it is important to understand the public's potential risk should a storm of this nature be forecasted. Section 2.5.7 of the Technical Data Report contains further discussion of surge heights at the New Bedford Hurricane Barrier.

4. Although behavior during a hurricane evacuation is difficult to predict, two overriding factors influence whether or not residents will evacuate: 1) the actions by local officials; and 2) the perceived degree of hazard at their location. The results of this study indicate that when officials take aggressive action to encourage people to leave their homes, evacuation rates increase by approximately 25 to 50 percent. It has also been found that the time at which people mobilize and evacuate is closely related to local officials' actions. During evacuation proceedings it is recommended that clear and consistent warnings are broadcasted to the public at risk to supplement "door to door" warning efforts.

5. The Shelter Analysis determined that the expected shelter utilization is greater than the reported shelter capacity in several of the study communities. These communities are encouraged to continue to work to identify additional public shelters.

6. The study presents clearance times for 18 hurricane evacuation scenarios, each varying by the intensity of the approaching hurricane, the response time of evacuees leaving their homes, and the background traffic condition at the start of the evacuation. For the Cape, a 10-hour clearance time is recommended for evacuations occurring during the daytime; and an 11-hour clearance time is recommended for evacuations which occur late at night or early in the morning. For all off-Cape study communities, a 7-hour clearance time is recommended for evacuations occurring during the daytime; and a 9-hour clearance time is recommended for evacuations which occur late at night or early in the morning.

<u>Clearance times developed for this study do not apply to the communities of Dukes and Nantucket Counties</u>. It is recommended that those communities continue to develop their hurricane preparedness plans to ensure safe evacuation from the islands prior to a hurricane threat for those who choose to leave the islands, and safe sheltering of those who choose to stay on-island.

7. To ensure suitable evacuation times are used in hurricane evacuation decision-making, it is important that State and local officials investigate existing communication and warning procedures and establish an appropriate amount of dissemination time. Dissemination time is a critical component of evacuation time. Failure to include this time as part of total evacuation time may substantially underestimate the time required to complete evacuations safely. It is recommended that officials refer to the Hurricane Bob Preparedness Assessment for Coastal Areas of Southern New England and New York, May 1993 for information that may be of assistance in quantifying dissemination time.

8. It is recommended that decision-makers use the Decision Arc Method outlined in Chapter Eight to assist in determining if, and when, a hurricane evacuation should be conducted. The method requires that decision-makers have access to the latest Tropical Cyclone Marine Advisories and Tropical Cyclone Probability Advisories issued by the National Hurricane Center.

9. It is recommended that the Massachusetts Emergency Management Agency continue to coordinate with the Massachusetts State Police to improve traffic flow at the Bourne and Sagamore rotaries. It was found in the Transportation Analysis that such measures could reduce roadway clearance times by up to 1½ hours.